With the author's compts

A POPULAR SKETCH

OF

ELECTRO-MAGNETISM,

OR

ELECTRO-DYNAMICS;

WITH PLATES OF THE MOST APPROVED APPARATUS FOR ILLUSTRATING THE PRINCIPAL PHÆNOMENA OF THE SCIENCE,

AND

OUTLINES OF THE PARENT SCIENCES

ELECTRICITY AND MAGNETISM.

By FRANCIS WATKINS,

Curator of Philosophical Apparatus in the University of London.

LONDON:

PRINTED FOR JOHN TAYLOR,

BOOKSELLER AND PUBLISHER TO THE LONDON UNIVERSITY,

30, UPPER GOWER-STREET:

DEIGHTONS, CAMBRIDGE: PARKER, OXFORD:

AND

WATKINS AND HILL, PHILOSOPHICAL INSTRUMENT MAKERS,

5, CHARING-CROSS.

1828.

[*Price Three Shillings.*]

LONDON:

PRINTED BY RICHARD TAYLOR,

RED LION COURT, FLEET-STREET.

ALERE FLAMMAM.

INTRODUCTION.

The following pages are intended to convey to the reader a plain, clear and concise account of the most important phænomena of the science of Electro-Magnetism, or Electro-Dynamics; a science which ever since its discovery has engaged the attention of many eminently learned and scientific men in every civilized state.

This science is of great importance to the philosopher and to the world; as it will probably lead to a more intimate, if not a perfect, knowledge of Electricity and Magnetism, and thus be the means of ascertaining that Electricity and Magnetism are either distinct and separate principles, or that they are one and the same principle differently modified.

Several valuable papers on the subject, by Mr. Faraday of the Royal Institution, have been published in the Quarterly Journal of Science, Literature, and Arts; and in the Annals of Philosophy. The subject has been treated of in an Appendix to Mr. Barlow's Essay on Magnetic Attractions; and there is also an article in the Encyclopedia Metropolitana on this subject. No distinct work on Electro-Magnetism had appeared in England, until Professor Cumming published a translation of M. I. F. Demonferrand's "Manuel d'E'lectricité Dynamique." But

as many persons may wish to be acquainted with the subject, who, from not being familiar with mathematical expressions and formulæ, would have a difficulty in perusing Professor Cumming's work, this Popular Sketch has been compiled; and to assist the same class of inquirers, and in the hope of spreading over a wider field, a more general knowledge of the parent sciences, Electricity and Magnetism,—an outline of these sciences has been carefully traced.

The plates exhibit the best apparatus for showing the leading phænomena of the science; and copious instructions are given, as to the best mode to be pursued in the manipulation.

No claim is made to originality in the science: all that is intended, is to lay the facts before the student in such language as will make the matter clear to him; avoiding theoretical disquisitions, as well as those numerous theories which have been advanced, many of which, although ingenious and plausible, are very far from being satisfactory.

A

POPULAR SKETCH

OF

ELECTRO-MAGNETISM.

ELECTRICITY.

ELECTRICITY is a principle supposed to be inherent in all bodies animate and inanimate, and is rendered evident either by friction, by pressure, by contact, or by the disturbance of the equilibrium of temperature in a metallic body.

The ancients were aware of the fact that a piece of amber subjected to friction acquired the property of attracting light bodies. Similar and analogous appearances have in later times been found to present themselves when other substances were submitted to the same process, and the same phænomena are developed in various ways by various substances. Bodies which when subjected to friction are found to possess an attractive power, are said to be excited, and are called *electrics;* while bodies which give no signs of electrical excitement under similar circumstances are called *non-electrics.* This is not a perfectly correct view of the subject, although it is a convenient mode of marking the distinction between that class of bodies which transmits electricity freely over its surface, and those substances that are apparently incapable of affording it a passage, or so imperfectly as not to be perceptible. The terms *perfect* and *imperfect* conductors are more appropriate and apposite; and thus two general divisions may be formed, under one or the other of which, all substances may be classed.

It is our intention in this slight sketch to treat only of the effects

presented by electricity, and not to enter into any theoretical disquisition as to the primary cause of electrical excitation: it is enough for our purpose, to know that such a principle exists, possessing certain properties; and it is only to those properties that we shall direct our attention.

It will be observed that we frequently speak of "the electric fluid," and "currents of electricity." But it must be remembered that these expressions are only made use of for convenience; for we know not whether electricity be material or a peculiar affection of matter, nor have we any proof of the existence of any current: and all that is intended to be understood is, that the effects presented are similar to those which would take place if a fluid subjected to certain assigned laws of action really existed. "Bodies in their natural state, having their natural quantity of electric fluid, are altogether inactive on each other, by making this natural quantity such that its mutual repulsion exactly balances its attraction for the common matter—it follows that we must deduce all the electric phænomena from an excess or deficiency of electric fluid." All the phænomena hitherto known may therefore be explained in a simple and easy manner by this theory, which was first developed by Dr. Franklin. The redundant state of a body is called *positive* or *plus* electricity, and the deficient state designated *negative* or *minus* electricity. The system of Franklin is generally adopted in this country; but some of the continental philosophers have recourse to the theory proposed by Du Fay, and afterwards more extended and combined by Symmer; according to which it is imagined, that instead of a single electric fluid there are two distinct fluids, producing two opposite electrical forces, viz. the positive or *plus*, and the negative or *minus:* the former, from its being excited by friction of glass, was called vitreous electricity; and the latter was termed the resinous electricity, from its being supposed to be principally produced by the friction of some resinous body; and thus the *vitreous* electricity of Du Fay answers to Franklin's *positive* electricity, and the *resinous* to what he named *negative* electricity. We shall make use of the language of the Franklinean theory, as being the most convenient: and when we speak of *plus* electricity, it must be understood as expressing the redundant state; and on the contrary, where the electric fluid is considered deficient, it will be termed *minus* electricity.

Whether we admit two distinct fluids, or only one in an overcharged and deficient state, this general law will be found in all cases to prevail. Substances similarly electrified are mutually repulsive to each other: and on the contrary, bodies dissimilarly electrified are found mutually to attract each other; the attractive and repulsive forces varying inversely as the squares of the distance.

These effects may be shown in the following manner:—Let a small hollow paper cylinder be freely suspended by a piece of silken thread, and by presenting to it a glass tube that has been well rubbed with a silk handkerchief, the cylinder will be immediately attracted, and adhere for a few moments, and then detach itself; and on again presenting the glass tube to the cylinder, it will recede. If the cylinder be touched with the finger, a repetition of the two original phænomena (attraction and repulsion) will be obtained. Hence, by the theory of Franklin, we draw the conclusion, that the attractive and repulsive qualities of electricity are dependent upon the different relative proportions in each containing body, with respect to its capacity, and to the different relative proportions contained in these bodies with respect to one another.

The opposite electrical states may be rendered more plain by the following method:—Let the electricity be excited on the glass by friction as before, and communicate the electricity to the cylinder so as to produce repulsion; rub a piece of sealing-wax, and bring it near the cylinder, and it will be attracted instead of being repulsed, as in the former case. The converse experiment may be made by touching the cylinder with the sealing-wax which has been excited, and after a short time it will be repulsed: if then a rubbed glass tube be brought near to the cylinder, it will be attracted. Thus we see that there is a material distinction between electricity excited by friction on glass and on sealing-wax; and hence it is evident that there are two opposite states of the same fluid. This important fact may be elucidated in another way:—If two cylinders be suspended by silken threads, and a piece of sealing-wax be rubbed with a piece of dry warm flannel, both cylinders will be electrified by touching them with either the sealing-wax or the flannel, and they will repel each other; but if one cylinder be electrified by the wax, and the other by the flannel, they attract each other. The same applies to the glass and the silk.

We should premise, that the term electrical repulsion is here

used merely to mark the appearance of the phænomenon, the divergence being, no doubt, due to a new attractive power acquired by the electrified cylinders for the surrounding bodies.

The different conditions of the exciting and excited bodies are explained in this way :—When flannel and sealing-wax are rubbed together, a portion of the inherent electricity leaves the wax and enters the flannel; the latter is therefore said to be electrified *plus*, and the former *minus*. If glass be rubbed by silk, the silk loses some of its electricity, and becomes *minus;* and the glass gains electricity, and thus becomes *plus*.

Another most important principle of electrical action has been termed induction or influence, words intended to express that species of action which results from the approximation, without contact, of an unelectrified to an electrified body. If any insulated substance be electrified, and opposed to an insulated conductor, but not within a striking distance, that end of the insulated conductor to which the electrified body is presented acquires an opposite electrical state to that of the electrified opposing substance; and the insulated conductor is said to be electrified by induction. If the electrified substance be removed from the conductor, every electric sign ceases; proving that no electricity has been communicated to the conductor, and the electrical appearance produced arises only from the unequal distribution of the inherent electricity of the conductor during its approximation to the electrified body. Nearly the same effect will be produced whether the conductor be insulated or not. Electricity excited by induction on imperfect conductors is not instantaneously restored to its original state of equilibrium by removing the inducing body, nor is it immediately excited to the full extent which the circumstances admit on presenting the excited to the unexcited body.

The properties of induction are of considerable importance as furnishing the means of accumulating the electric fluid, and the Leyden jar is employed for that purpose. This jar is of glass, covered inside and outside with a metallic coating to within a short distance of the mouth. A metal rod is passed through a wooden cap in the mouth of the jar, its lower end touching the metal coating inside of the jar, the upper projecting three or four inches above the cap, and terminating in a ball. If the ball be brought in contact with an electrified body, the inner surface will be found in

the same condition as the electrified body; the external surface in the opposite state, by induction; which may be proved by discharging the jar.

That the electric fluid is capable of considerable tension may be shown in many ways; but the faculty of electrical transmission is very different in different bodies, and electricians have therefore called the substances that afford a ready passage to electricity, conductors; while others, through which the fluid cannot pass, are named non-conductors. Substances thus classed were formerly inaccurately termed electrics and non-electrics, from the supposition that the former name indicated an incapacity for electrical excitation by friction, and the latter denoted the contrary property. This is not the fact; for electricity may be excited in all solid substances by friction. A metallic substance when rubbed in the same manner as a piece of smooth glass tube, does not, it is true, exhibit any trace of electrical action, for the electricity is no sooner produced than it is conveyed (by the conducting power of the metal) to the earth, through the body, by means of the hands; but if a non-conducting substance be interposed as a support or handle, then the metallic rod when rubbed with dry fur, exhibits an attractive property by attaching to itself any light body it may be presented to.

Among the good or perfect conductors of electricity may be enumerated all the metals, charcoal, plumbago, &c.; among the imperfect or non-conductors, acid and saline solutions, water, alcohol, ether, metallic oxides, oils, glass, resins, &c. The two latter bodies are usually employed as insulators.

For exhibiting and obtaining ordinary electricity, many kinds of apparatus may be employed; but those most in request are the cylinder and plate machines. The first-named machine is a glass cylinder, made to revolve on its axis by a handle; the electrical excitation is produced by the friction of a cushion, and the electric fluid is collected on a smooth metal cylinder called the prime conductor. The other machine is a circular disc of glass, mounted on an axis; and motion being given to the plate, as in the former case, the electricity is excited by the rubbing of cushions: the prime conductor is a bent brass rod. Both constructions are mounted on mahogany frames, and the parts, where necessary, supported on glass pillars as insulators.

In this very brief outline of the phænomena of electricity, the terms applicable to all cases of electrical excitation have, we trust, been explained in a sufficiently clear manner; so that when made use of hereafter, the reader may readily understand the sense intended to be conveyed by the terms used. We therefore hasten to the consideration of that peculiar species of electricity which has been supposed to be elicited by contact, as it is that kind mostly employed in the experiments of Electro-magnetism. It is called Hydro-electricity, Galvanism, or Voltaic electricity; the latter after the name of the celebrated Italian philosopher Volta, who found that if two insulated discs of dissimilar metals were placed in contact, on separation they exhibited evident signs of being in opposite electrical states,—the one being plus, the other minus, or positive and negative; and thus proved that the sudden and violent muscular contractions which take place when the nerves and muscles of the limb of a frog are respectively in contact with different metals, is due to electricity, and not to any peculiar power existing in the muscular fibre and nerve as was supposed by Galvani, the original discoverer. In all cases the electricities may be respectively distributed over any conducting surface which may be placed in communication with the electrified bodies. From this property of metals, they have derived the name of *motors* of *electricity,* and the process which takes place, *electro-motion.*

As the quantity of electricity excited by any two pieces of metal is small, it is necessary to obtain an increased effect by employing numerous pairs of metallic plates, taking care to retain the connection in such a manner that the electricity elicited by each pair be diffused through the whole train; and also that each member of the series consists either of one imperfect and two perfect, or of one perfect and two imperfect conductors.

The method of arranging the metallic plates to form a voltaic combination is susceptible of considerable variety: that invented by Volta, consists in placing dissimilar metals in contact, and laying on them a piece of flannel of the same size as the plates, (moistened with water or a saline solution,) and on that another pair of metals, then a piece of moistened flannel, and so on, the number of alternations depending on the pleasure of the experimenter, and the power required: the relative position of each pair *must* be preserved through the whole series; and that metal which is undermost

in the first combination, must be also undermost in the last. For the convenience of experiments the metallic discs are now usually soldered together, and when piled are supported by three upright pieces of wood, which are attached by their lower ends to a base or stand. An apparatus of this kind of thirty or forty repetitions, two inches diameter, is sufficient to affect the gold leaf electroscope, and to give a smart shock, as may be felt by applying the hands to the upper and lower extremities of the pile (the hands should be previously moistened, as the dry skin is a bad conductor): the effect thus produced is presumed to be analogous to the discharge of a Leyden jar, by an annihilation of the opposite electricities, plus and minus.

A peculiar feature in voltaic electricity, and wherein it differs from ordinary electricity, is, that the equilibrium is no sooner restored, than it is again disturbed; for the conditions which originally excited it are still maintained, and therefore a continued current is kept up along the wire, or any conducting substance that may connect the extremities of the combination. The pile of Volta is now not much in request (excepting occasionally for medical purposes), because other modes have been devised for forming the combination in a far more œconomical and convenient manner.

The first of these was the invention of Mr. Cruickshanks, who introduced the plan of soldering the metallic plates together, and placing them in a long and narrow mahogany trough, with grooves cut opposite to, and at equal distances from, each other; the pairs of metals are thus retained in their positions by cement, and are so arranged that similar metals are always on the same side. The apparatus is rendered active by filling the interstices between the pairs of plates with acid or saline solutions.

The *couronne des tasses* of Volta probably suggested to Dr. Babington the alteration he proposed, which is effected by using a trough of Wedgewood's ware, divided into several partitions or cells. In this arrangement, each cell receives a plate of zinc and copper, not in contact, but the communication is carried on through the medium of the fluid in which they are immersed. The copper disc of one partition is attached to the zinc of the next by a metallic arc: all the plates are affixed to a wooden beam or rod, by which contrivance they may be placed in, or removed from the cells at pleasure.

To this apparatus Dr. Wollaston recommended the important addition of surrounding the single plates of zinc with copper; the power of the zinc being obviously increased by extending the copper plate so as to oppose it to every surface of the zinc, contact of surfaces being prevented by small pieces of cork or wood. This apparatus is best adapted to all the researches in which there is a demand for *quantity* as well as *intensity* of electric fluid.

For experiments in electro-magnetic science, a battery, similar in construction to the calorimotor of Professor Hare, is to be preferred, as being the most œconomical and affording greater facilities to the experimenter. It consists of two fixed hollow concentric cylinders of copper, having a moveable cylinder of zinc placed between them: one great advantage which this construction possesses is, that after every experiment the zinc cylinder may be taken out, and the oxide which is formed on its surface removed; the battery being thus restored to its original state of activity. This contrivance, we believe, is due to Mr. Sturgeon of Woolwich, and it will be seen how admirably it is adapted for the purposes to which he has applied it.

A number of batteries may be joined together by merely arranging a metallic communication between the copper extremity of one battery and the zinc extremity of the other. By this method of multiplying the number of plates we obtain electricity of a high *intensity*, and the proportion is as nearly as can be judged an arithmetical one. By enlarging the size without increasing the number of alternations, we gain not in *intensity*, which remains exactly the same, but in *quantity*. The term *quantity* is employed to express the real quantity of electric power in a body, and *intensity* or *tension* its power of transmission through imperfect conductors.

The relative effects of *quantity* and *intensity* were admirably illustrated by the experiments instituted by Mr. Children, whose voltaic combination consisted of plates thirty-two inches wide and six feet high. The effect upon perfect conductors was intense, but upon imperfect conductors feeble. Different degrees of chemical action are produced on the metallic plates by the various fluids used to excite the voltaic apparatus; and the more powerful the action produced, the more transient is its duration.

To obtain an apparatus which would continue in force during

any required time, M. De Luc contrived an instrument which he called "the electric column." It is formed on precisely the same principle as Volta's pile, but with this important addition; that the imperfect conductor instead of being a fluid is a dry substance, and writing-paper is preferred for this purpose. The column is usually arranged in a glass tube which should be as free from moisture as possible, and the alternating pairs of plates with the paper are regularly arranged within it; a brass cap is attached to each extremity of the glass tube, and each cap has passing through its centre a wire with a screw, which serves to press the plates closer together, and to secure contact with the outside metallic plate at both ends of the series. A combination of this kind, if kept perfectly dry and insulated, composed of very thin pairs of plates of silver and zinc in contact,—each such pair being separated from the next pair by a disc of writing-paper,—has been found after the lapse of several years undiminished in its effects on the gold leaves of an electroscope. Although this apparatus gives evidence of considerable electric power, it has no chemical action; hence it has been supposed that to produce chemical action, it is absolutely necessary that a *fluid* be employed as the interposed media between each pair of the metals in the voltaic combination.

The properties of a voltaic combination may be arranged under four heads. 1. Its electrical phænomena: 2. Its production of light and heat: 3. Its extensive agency as an instrument of analysis: 4. Its inducing magnetism on steel bars.—We shall propose examples of each of these properties.

1. *Its electrical phænomena.*—If a wire connected with either of the extremities of a voltaic battery be brought in contact with a delicate instrument termed an electroscope or electrometer, which by its construction may indicate very feeble electricity, the fluid emanating from each end of the combination will produce essentially different effects. This may be shown by testing it with glass excited by friction of silk, or by sealing-wax excited by friction of flannel: and as the best effects are obtained in electro-magnetic science by the use of a battery constructed of one large pair of plates, wherein the plus electricity is supposed to pass from the copper through the connecting wire to the zinc, and from the zinc through the interposed fluid to the copper; we shall, when alluding to the electric stream issuing from the

copper end of the battery designate it *plus*, and the term *minus* will in contra-distinction be employed to express the *zinc* end of the battery. When a small quantity of electricity is made to pass through the nerves of living animals or such as have been recently killed, it occasions a tremulous motion and contraction of the muscles. *e.g.* Place a flounder on a plate of zinc with a small piece of silver upon its back, and violent convulsions will be produced every time a communication is made between the metals; the connecting wire must be a good conducting substance, or no effect will be produced. A similar circumstance will happen if you pass a slight shock from a Leyden jar through the limbs of a frog but lately deprived of life. If a silver plate be placed upon a plate of zinc of larger dimensions, and a leech or worm be put upon the silver; as long as the reptile remains in contact with the silver only, it will betray no uneasiness, but on its elongating its body so as to touch both the silver and zinc plates at the same time, it immediately recoils as if it received a painful shock.

2. *Production of light and heat.*—Sir H. Davy, with the powerful voltaic combination of the Royal Institution, consisting of two thousand pairs of four-inch square plates, was enabled to produce the most intense artificial light ever seen, excepting perhaps that exhibited by the combustion of lime with the mixed gases. He says: "When pieces of charcoal about an inch long and one-sixth of an inch in diameter were brought near each other, within the thirtieth or fortieth part of an inch, a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness; and by withdrawing the points from each other, a constant discharge took place through the heated air, in a space equal at least to four inches, producing a most brilliant ascending arch of light, broad and conical in form in the middle. When any substance was introduced into this arch, it instantly became ignited; platinum melted as readily in it as wax in the flame of a common candle; quartz, the sapphire, magnesia, lime, all entered into fusion." Hence it is evident that electricity evolves both light and heat.

3. *Extensive agency as an instrument of analysis.*—In the hands of the chemist the voltaic battery proves of infinite use and importance, in consequence of its great power as an agent of transfer and decomposition. By its aid, the law and order of chemical affinity are subverted and superseded, and substances which re-

sist all other attempts at decomposition, yield to its prodigious power, and are resolved into their ultimate elements. When any solution of a neutral salt is placed within the influence of a voltaic combination, various phænomena occur; the acid collects round one of the wires, the alkali round the opposite wire. If two glass vessels containing infusion of red cabbage be inverted in basins filled with a solution of sulphate of soda and connected by moist cotton, the blue liquor in one of the vessels will become red by the accumulation of the acid, and green in the other vessel by the attracted alkali;—reverse the connecting wires, and the red liquor will be seen first to resume its original colour, and after a short period become green, and the green portion of fluid will acquire its original blue tinge and then become red. Thus we see that acids and alkalies may be transmitted through delicate vegetable colours, and made to change them—restore them—and again to change them.

The powers of decomposition possessed by the pile were first observed in its action on water. When connecting wires from the extremities of a battery are made to communicate with that fluid, and when those wires are of a metal not susceptible of oxidization; bubbles of gas are evolved at both wires, and may be collected separately or conjointly. When a metallic solution is acted upon instead of water, the metal is revived round a particular connecting wire, and no gas is liberated. It was by the agency of an extensive voltaic apparatus that Sir H. Davy succeeded in his brilliant course of experiments which affected the decomposition of the alkaline earths, and enabled that eminent philosopher to determine the constitution of this class of bodies, which had for ages been considered as simple and undecomposable. So irresistible indeed are the powers of the voltaic combination, that the most solid aggregates and firmest compounds when submitted to its action, assume simpler forms of matter.

The principles of the voltaic pile have been applied for obviating the injurious effect of sea-water upon the copper sheathing of vessels, but with imperfect success; for although the voltaic action has been prevented, yet, in consequence of the surface of the copper being preserved from oxidation, the smaller class of marine insects are found to affix themselves to the copper, through which some of them have pierced holes.

4. *Inducing magnetism on steel bars.*—It is known that lightning

possesses the power of reversing and destroying the polarity of a magnetic needle, and iron bars when subjected to its influence have been found to exhibit magnetic properties not before distinguishable. Attempts were accordingly made to induce magnetism by the electrical machine, and also by voltaic combinations, but with imperfect success. In the autumn of 1819, Professor Œrsted made his discovery, and proved that the voltaic and magnetic fluids acted reciprocally upon each other; and his experiments formed the basis of electro-magnetic science. Subsequently M. Arago succeeded in magnetizing needles by a small pile; the form of the connecting wire was a helical coil: by this simple arrangement the maximum effect was produced. If a steel needle be inserted in a coil and removed again immediately, it will become a permanent magnet. Sir H. Davy about the same period magnetized steel needles, by placing them transversely to a wire connecting with the plus and minus extremities of a voltaic combination: he also rendered a needle magnetic by placing it across a wire along which a charge from a common Leyden battery was transmitted.

A very slight degree of ordinary electricity is sufficient to produce magnetism in a needle. If a helix be prepared, and an unmagnetized needle placed in its interior, and one end of the helix held in the hand, the other brought near the conductor of an electrical machine, and sparks passed to it,—after a number of sparks have been taken, the needle will be magnetic. From experiments we may conclude that the identity of electricity and lightning is established.

In performing experiments with the voltaic battery, and more especially when that apparatus is used for showing the phænomena of electro-magnetism, *perfect* metallic contact of the several repetitions of connecting wires is essential to complete success. It is necessary that all the points of the wires should be cleaned, filed, or rubbed with emery or glass paper, or that they should be amalgamated, so that a current of electricity transmitted through the several wires should meet with no interruption, and that its passage should be the same as if only one wire were employed. Mercury is used in connecting the points, and is placed in cups made for that purpose, in the various electro-magnetic apparatus; and although perfectly clean points to the connecting wire will generally answer the purpose, to obtain the best results they must

be amalgamated: the most ready and perhaps the best method to accomplish this, is to rub the parts intended for insertion in the cups with nitrate of mercury; to obtain which, place a globule of mercury in a glass vessel containing a small quantity of diluted nitric acid; upon dipping the points into the solution and moving them about in contact with the metal, they will become amalgamated on the surface. The ends of the wire thus amalgamated speedily decay: to prevent the decay, after the experiments are concluded, the wires should be well washed in water, wiped dry, and the mercury removed. Copper next to silver wire is the best connecter, and also the best conductor of electricity. The wire should be as thick as can be conveniently used, and as short as possible; contact may be formed by twisting wires together, but this will seldom be found to be sufficient; and therefore the wires must beamalgamated previously, or be more closely brought together by binding a smaller wire round them, care being taken that the wires are perfectly free from grease or dirt.

Platinum wire is also extremely useful, and not subject to decay like the amalgamated copper, from its power of resisting the action of the mercury upon it; but the great expense of that metal prevents its being commonly employed. Considerable advantage is gained by employing in electro-magnetic experiments mercury free from dirt or oxide, as the parts of the apparatus which are intended to move, do so with greater facility when the surface they travel on is quite clean; besides, contact between the moving points and the mercury is better preserved. Should the mercury used be not clean, it is advisable to cover the surfaces of such portions as are in the troughs or cisterns where the moving parts dip, with diluted nitric acid; a thin layer is sufficient to dissolve any film. The force generated by the mutual action of the electrified wire and the magnet is considerable; but when the arrangement is such as to cause rotatory motion, there should be as little friction as possible, the parts that have motion should but just touch the surface of the mercury. Mercury becomes dirty from being used; and the most ready way to remove any impurities it may imbibe is, after the experiments are completed to place the metal in some glass or earthenware vessel, such for instance as a gallipot; and before placing on the cover, which should not be air tight, to pour on to the mercury a little diluted nitric acid, there to remain until the

mercury is again required. By this plan a constant supply of nitrate of mercury for amalgamation is produced; as the aqueous portion of the solution evaporates, and the acid combined with particles of the metal crystals are formed on the top. When an amalgamation is necessary to be formed, take a piece of the crystal, place it in a small glass vessel, and mix it with a little water; on introducing a clean metallic wire into the solution, the end of the wire immersed becomes coated with mercury. Such parts of an apparatus as cannot easily be dipped into the solution may be amalgamated by being rubbed with a wire that has been already amalgamated; and as the mercury is transferred from the rubbing wire, it may be renewed by again immersing it in the solution.

Until within these few years it has been usual in performing electro-magnetic experiments to operate with extensive batteries and small magnets. The expense attending the purchase of a large voltaic combination, and also for acid to excite it, the difficulty of keeping it in great activity, and the inconvenience arising from the quantity of gas evolved during the process, induced Mr. Sturgeon to institute a series of experiments, with a view of ascertaining if any particular ratio of electric and magnetic power was necessary for the development of electro-magnetic phænomena; and he succeeded in proving that precisely the same effects were produced when powerful magnets and a feeble electric force were employed, as were originally produced when small magnets and extensive batteries were used. The facilities thus afforded to the amateur in science of experimenting on electro-magnetism at so small an expense and comparatively little trouble, will no doubt tend to a dissemination of the knowledge of the peculiar and extraordinary facts of this science, and aid its progress towards the development of others which probably are as yet unknown to us. The cylinder-formed battery recommended has cups to hold mercury, affixed to wires soldered to both the copper and zinc cylinders, by which contrivance, contact between the cylinders and the connecting wire may either be preserved or broken as occasion requires.

As other forms of the voltaic combination are sometimes (even now) used in performing experiments in this branch of physical science, we think it right to make one or two remarks on the method to be pursued for obtaining the best results from them. That arrangement of the voltaic battery that affords the greatest *quan-*

tity of electricity is decidedly to be preferred, if not absolutely necessary. The power and activity displayed by the battery mainly depends upon the strength of the diluted acid used; and as the acids sold in the shops vary considerably in their value, it is difficult to state in what precise proportions they should be mixed, and philosophers are not agreed as to the best acids to be employed. Some recommend muriatic, others nitric, others sulphuric acid; but we believe the most approved mixture for an extensive series consists of two parts in bulk of sulphuric acid, and one part of nitric acid, with one hundred parts of water. The proper strength may be ascertained by inserting into the diluted acid a piece of zinc, noting the effects produced; the gas evolved should ascend in bubbles scarcely visible; but should a violent action be produced, and bubbles press upwards with rapidity and of large size, water must be added; on the contrary, should the mixture exert no sensible effect on the metallic plate, an addition of acid is necessary. When a battery is employed consisting of one, two, or more pairs of large plates, and it is intended to excite as large a *quantity* of electricity in a given time as possible, a stronger solution than that before mentioned may be used; viz. one part nitric acid and eleven parts of water: this will put the battery in a state of high activity, but its energies will be of short duration; these proportions for the diluted acid will be found to be best for the cylinder battery, which we have before strongly recommended to be used in electro-magnetic experiments.

In the employment of batteries of the form suggested by Dr. Babington, the plates should be withdrawn from their cells, and care be taken in pouring in the diluted acid, that the cells are not so full as to flow over when the plates are immersed; and particular attention should be paid in returning them, that they are properly introduced, and that the zinc plate of one pair be in the same cell with the copper plate of the contiguous pair. Batteries of this construction usually consist of ten or twelve pairs of plates, and they may be used separately or conjointly by the last copper plate of one series being inserted into the same cell with the first plate of zinc of another series, precaution being taken that the plates are all arranged in the manner before directed. The two extremes of any voltaic combination are called the poles, and

the connecting wires should be in metallic contact with these poles. It is necessary, when applying the terms *plus* and *minus* to the poles of a battery, to consider whether the combination consist of one pair of plates or several, as in the composite battery. It is observed that when a plate of zinc and a plate of copper have been placed in contact, on their separation the zinc plate indicates *plus*, and the copper *minus* electricity; it is therefore inferred that when two plates of these metals are immersed in an acid solution, that the zinc communicates a portion of its *plus* electricity to the fluid, and the copper communicates its *minus* electricity to the fluid; there is therefore necessarily an accumulation of *minus* electricity in the upper portion of the zinc, and of *plus* electricity in the upper portion of the copper; the connecting wire applied to the zinc receives its accumulated *minus* electricity, and the wire in contact with the copper receives its *plus* electricity. When only one pair of plates compose the battery, the copper end is termed *plus*, and the zinc end *minus*. When a composite battery is employed, the zinc end is designated *plus*, and the copper end *minus*, for this reason, that for the preservation and continuance of the current of voltaic electricity, a fluid must be interposed between the plates. The *plus* electricity from the zinc passes through the fluid to the copper, and the *minus* electricity from the copper to the zinc; and as the terminal plates of the composite battery at either end are not in contact with the fluid, but in connection with a metal of a different description; it follows, that the last copper plate in contact with the fluid, communicates its accumulated electricity to the zinc plate united to it, and by this zinc plate it is transferred to the connecting wire. Hence this extremity of the combination is termed the *plus* pole. At the opposite end of the combination, the last zinc plate in contact with the fluid communicates the electricity it receives from the fluid to the copper plate united to it, that copper plate conveys it to the connecting wire; consequently this extremity of the combination is named the *minus* pole.

As a battery which developes *quantity* is necessary for electro-magnetic experiments, and as this is best obtained by a battery of the construction recommended, consisting only of one pair of plates; it must be remembered, that in our remarks on electro-

magnetic science, when referring to the plus pole, means the copper end, and the minus pole the zinc end.

It has been shown that electricity excited by a systematic arrangement of plates of dissimilar metals in pairs, and an interposed acid solution, develope certain phænomena. To account for these phænomena, various theories have been advanced. Those that claim the most attention were suggested by M. Volta, Dr. Wollaston, and Sir H. Davy.

The first-named philosopher supposes that electricity is produced by the association of the two metals, the original electricity being disturbed by the contact; and that the fluid employed acts merely as a conductor of the electric stream.

Dr. Wollaston supposes that the oxidation of the metals is the original cause of the electric phænomena; and in support of the views entertained by that eminent philosopher, we beg leave to notice that an "electric column" may be formed by one metal only. If a series of plates of zinc, with one side polished and the other side unpolished, be arranged in regular order with all the polished surfaces in the same direction, and a stratum of air be interposed between each plate; on a communication being made by a connecting wire from either extremity of the combination, to the cap of a delicate electroscope, the gold leaves will diverge, indicating that an electric circuit is formed. The electrical action, it is submitted, is here produced solely by the oxidation of the polished surface of the metal disturbing the inherent electricity of the plates.

Sir H. Davy conceived the electricity to be originally excited by the contact of the metals, preserved and continued by the chemical action of the interposed acid solutions; and that the chemical change, although not the primary source of the disturbance of the electricity, was essential for its development in considerable quantities.

The science of electricity embracing such an extensive field of inquiry, cannot but be very imperfectly treated of in the small space allotted for the subject in our little treatise; but we hope a competent idea has been conveyed of the several leading phænomena of the science, and also of the signification of the terms employed to designate those phænomena. The various voltaic apparatus have been explained; and their several merits pointed out: the

most approved method of manipulation, which has been adverted to in a manner sufficiently explicit, we trust, as to enable the reader to select the apparatus best adapted for his experiments, and to pursue that plan which will obtain the best effects from it.

MAGNETISM.

If a rod of iron be freely suspended in a horizontal position, it assumes a particular direction; and when subjected to the process of twisting, filing, or percussion, it acquires the property of attracting and of being attracted by other pieces of iron brought near to it. This property does not belong exclusively to iron; for nickel, cobalt, bismuth, and several rare metals and minerals are found to develope similar phænomena, although in a very feeble manner, when compared with that of ferruginous matter.

Bodies which possess the property of attracting and of being attracted by iron, are called magnets: they are of two kinds, natural and artificial. The natural magnet is a mineral substance called a loadstone; the artificial magnet is a hardened bar of steel to which the magnetic property has been communicated: it is superior to the loadstone, as it possesses all its qualities, with a greater uniformity of texture and of distribution of the magnetic power, and the advantage of being moulded into any required form.

When a bar of steel impregnated with the magnetic fluid is immersed in iron filings, there will be a greater accumulation of the attracted particles at the extremities than at any other of its parts: and these terminal points of the bar are called its poles. The axis of a magnetic needle is an imaginary right line, coinciding with its boreal or northern, and its austral or southern, extremities: a plane at right angles to this line, passing through the centre of the needle, is the magnetic equator; and another plane, passing at right angles to the latter through the needle, is the magnetic meridian.

A fundamental principle of magnetism may be shown by freely suspending on its centre of gravity an artificial bar magnet, which

will then assume a direction nearly north and south. The bar may be drawn from this position; but when again left to itself, it will, after a few oscillations, invariably present the same end towards the north. As this happens in all parts of the world, it is inferred that magnetism pervades the globe, and that the needle is influenced by the magnetic power of the earth, which has been termed terrestrial magnetism. The suspended magnet, as before mentioned, has a tendency to arrange itself in a certain direction, the same end always pointing to the north. It is therefore usual to mark that extremity N. which is towards the terrestrial north pole; and S. that which is towards the south pole. As the same law prevails in magnetism as in electricity, similar poles repel, while dissimilar poles attract each other, with a force inversely as the square of the distance; the end of the magnetic needle which is marked N. (north), to indicate the direction to which it points, is in fact its south pole: and the same reasoning applies to the other extremity that points to the south, which is in reality its north pole, as it is attracted by the south pole of the earth. However, to prevent confusion, we shall in all our remarks on the magnetic needle adhere to those terms usually applied to its several ends, and designate that end *north* which points in that direction, and the other end *south* which points towards the southern extremity of the earth.

The directive property of a magnetic needle is of vital importance to the mariner: it furnishes him with an instrument called a compass, by the aid of which he is enabled to determine the several quarters of the horizon, and consequently to ascertain at any time the direction of a ship's course on the ocean. It is also extremely useful in many operations on land, particularly to the miner, the surveyor, and the traveller.

The common compass consists of a circular metal box, the bottom of which represents the horizon: from the centre of the bottom projects a steel pivot, upon which is suspended the magnetic needle; surrounding the steel pivot is a plate divided at its outer edge into three hundred and sixty equal parts or degrees; the several points of the compass are also marked upon it: the top of the box has a glass cover to protect the needle from the action of currents of air. In the mariner's compass the divided circular plate is a stiff card, affixed to the upper part of the needle, with the north and

south points made to correspond with the axis of the needle, and the whole balanced on the steel pivot: the compass-box is hung on gimbals, with its centre of gravity much below the points of suspension, to obviate the effects the rolling motion of the vessel would have upon the needle. In compasses thus constructed, the needle plays horizontally: to accomplish this, the needle is balanced *after* the magnetic property has been communicated to it; for if a light bar of steel be very delicately balanced on its centre, immediately on having the magnetic virtue communicated, it no longer preserves its horizontal position, but in ranging itself in the magnetic meridian is observed to have acquired the additional property of dip, the north pole apparently becoming the heaviest, and inclining below the horizon. The amount of this inclination depends upon the latitude of the place where the experiment is made. This angle is called the dip or inclination of the magnetic needle. The phænomenon was first observed by Robert Norman, an Englishman, in the year 1576, who constructed an instrument to ascertain the precise angle the magnetic needle would by its dip form with the horizon; and it is stated that 71° 50′ was the inclination he found. The Philosophical Transactions of 1823 contain a paper of Captain Edward Sabine's on this subject. "The experiments were made in August and September 1821 in the nursery-garden in the Regent's Park,—a situation far removed from the neighbourhood of iron; and their mean results gave 70° 03 as the mean dip of the needle. Comparing this amount with that obtained by Nairne in 1772, and by Cavendish in 1776, we obtained 3′·02 as a mean annual rate of diminution between 1774 and 1821, which is less by two-fifths than the mean annual diminution at Paris between the years 1798 and 1814, as deduced from the observations of Messrs. Humboldt, Gay Lussac, and Arago; whence it might be inferred, if sufficient dependence could be placed upon the accuracy of the observations, that the annual variation of the dip in this part of the world is greater now than it was forty years ago: yet if we take Whiston's determination of the dip in 1720 (75° 10′), we obtain between the years 1720 and 1724 an annual diminution of 3′·05, which almost exactly coincides with the rate found for the succeeding forty-seven years." Mr. Christie of Woolwich, taking the mean of forty observations, gave 70° 15′ 25″ in December 1821. In May 1824, the mean of forty observations 70° 10′ 5″.

The nature of the dip may be illustrated in a familiar manner by delicately balancing a steel needle, and then impregnating it with the magnetic fluid: its pole marked North, as before observed, will be depressed. Then if the magnetized needle so suspended be passed along a bar magnet, when the needle is over the south end of the bar, that point of the needle marked North will acquire a greater dip, and assume a vertical position at right angles to the bar. As the needle is made to pass along towards the centre, the angle of the dip will gradually lessen; and when it arrives at the equator of the magnet, the needle will be in a horizontal position. If the needle be now slowly advanced towards the north end of the bar, the south pole of the needle will incline, the amount of inclination progressively increasing until it arrives at the north pole of the magnet, when the South end of the needle will be directed perpendicularly to it.

Another curious and interesting fact is developed in the freely suspended needle, that its point of direction varies from the true north; and the angle formed is called the declination, or variation. When the north pole of the needle declines to the *east* of the true north, it is termed *east variation;* and when the declination is to the west, it is designated *west variation.* It has been stated that Columbus was the first person who discovered the variation of the compass needle; this was on the 14th of September, 1492: but it has been ascertained that the fact was noticed nearly two hundred years before. In the year 1580, the declination of the needle was 11° 15′ east; and in 1622 it was observed that the variation was less to the eastward, and progressively approaching the true meridian, at which it arrived about the year 1657; from which period it commenced a western variation until within the last eight or nine years: and at the present time it is again on its return to the true meridian, its greatest deviation having been about 24° 30′ west in London in 1818; consequently, the lapse of time between the magnetic needle being at zero and its arrival at the greatest western boundary, is one hundred and sixty-one years. Besides the annual variation, it is found that the magnetic needle has a diurnal variation: this fact was first observed by Mr. Graham in London in 1772. Subsequent experiments made by Mr. Barlow and Mr. Christie, show "that while the needle is directed to the north, its first motion commences very early in the morning to the

eastward; that it obtains its greatest deviation in this direction at about seven o'clock in the morning; from this time the easterly deviation diminishes (the motion of the needle being to the westward) till about half-past ten or eleven o'clock in the morning, when the deviation is zero, and when, it will be observed, the sun being upon the magnetic meridian, from this time the westerly deviation commences, and consequently the westerly motion of the needle continues till about half-past one o'clock, or two o'clock, when the westerly deviation is at its maximum, and then begins to diminish, the motion of the needle being now to the eastward; at about five o'clock the deviation again vanishes, and the needle points once more north and south (magnetic); but its easterly motion continues till very late in the evening."

An interesting series of observations and experiments were made at Port Bowen in the years 1824 and 1825 by Captain Parry and Captain Henry Foster, on the diurnal variation and diurnal intensity of the magnetic needle, an account of which is published in the Philosophical Transactions, for 1826.

Experiments in thermo-magnetism teach us that magnetical phænomena will arise from a disturbance in the equilibrium of temperature of metals, and perhaps of all bodies in nature: it has therefore been supposed that the diurnal variation of the needle and other peculiar phænomena developed by terrestrial magnetism are caused by the metals and other substances composing the crust of the earth being subjected to change of temperature by solar heat, acting on the suspended magnetic needle, and this action being modified by the rotation of the earth on its axis.

Mr. Christie observed that the magnetic needle made fewer vibrations and attained a state of rest much sooner when the compass was exposed to the solar rays, than when the experiment was repeated in the shade. Hence he infers, that the solar rays possess sensible magnetic properties. The same gentleman made a series of experiments to ascertain the effects of temperature on the intensity of magnetic forces; and he found that as the temperature of the magnets increased, their intensity diminished,—in direct contradiction to the notion of destroying magnetism by intense cold. From a temperature of 80° the intensity decreased rapidly as the temperature increased; and at above 100° a portion of the power of the magnet was permanently destroyed.

If solar light really affects the magnetic needle when vibrating under its influence, and this, too, independently of any heat it may impart, it will be necessary, while remarking the intensity of the magnetic needle in various parts of the earth, to observe whether or not the instrument be exposed to the solar rays during the observation.

The magnetic properties of solar light have been adverted to by several philosophers; and Professor Morichini of Rome announced in 1813, that he had succeeded in imparting magnetism to steel needles by exposing them to the violet-coloured ray of the prismatic spectrum.

Mrs. Somerville has stated, that magnetism was induced on small steel needles by enveloping one end of them in violet-coloured silk or paper, and exposing them to the influence of the solar ray. We think it requires the favourable result of future experiments to confirm the fact, that the violet-coloured ray of the prismatic spectrum induces magnetism on steel needles placed within its influence; for it is known that many of our most expert manipulators in experiments on natural philosophy have failed in repeating those of Morichini and Mrs. Somerville. Hence we are led to infer that the needles operated upon by Morichini and Mrs. Somerville possessed magnetic properties previous to their being acted upon by the solar ray; and that that magnetism escaped the notice of the experimenters when tested by them at the commencement of the operation. We wait anxiously for the decision of the question respecting the magnetic property of the violet-coloured ray; for if it be satisfactorily established that it does possess the power of influencing steel needles in the manner described, the fact will no doubt tend ultimately towards the improvement of our knowledge of the phænomena of terrestrial magnetism.

It is also conceived that polar lights, or the Aurora Borealis and Australis, exert an influence on the magnetic needle; and M. Arago asserts "that distant polar lights, even if they are not seen in a given place, exercise an evident influence on the direction of the magnetic needle there."

With respect to the fittest form of a steel bar for a magnetic needle, a great deal might be advanced; but we must limit ourselves to observing, that every care and attention should be bestowed on

the composition and uniform construction of magnetic bars intended for needles in experiments of research. The magnetic virtue should be imparted as uniformly as possible, although perfect uniformity cannot be attained. The extremities of the needle should terminate in sharp points, and the centre be of sufficient width to receive a brass cap. This cap should contain a small conical agate cup, on which the needle is to be balanced on a steel pivot, or it may be poised by a silken thread devoid of torsion: these methods apply only to a needle playing horizontally; a very different mode of suspension is necessary when the needle is intended to have a vertical movement, as in the case of the dipping needle.

The attention of the scientific world was called to the consideration of the induced magnetic properties of different metals, by a communication made by M. Arago to the French Academy of Sciences in the latter end of the year 1824. He observed that the metal rings with which magnetic needles are usually surrounded exerted a sensible influence on the needles, the effect of which was to diminish the amplitude of the oscillations; and as the result of some experiments which he made to prove this, he states "that a horizontal needle suspended in a ring of wood by a thread without torsion, being moved 45° from its natural position, and left to itself, made 145 oscillations before the amplitude was reduced to 10°. In a ring of copper the amplitude diminished so rapidly, that the same needle on being removed 45° from its natural position, only oscillated thirty-three times before the arc was reduced to 10°. In another copper ring of less weight, the number of oscillations between the arcs of 45° and 10° were sixty-six; the time of the oscillations appeared to be the same in all the rings."

The capacity of various metals for the development of magnetism by induction, may be exhibited by putting into rapid rotation metallic discs or plates in approximation with a magnet, and by vibrating metallic discs or plates between the poles of a horse-shoe magnet. Mr. Babbage "mounted a powerful compound horse-shoe magnet, capable of lifting twenty pounds, in such a manner as to receive a rapid rotation about its axis of symmetry, the axis being placed vertically in the line joining the poles, the poles being upwards. A circular disc of copper six inches diameter and 0·05 inch thick, was suspended centrally over the

magnet by a silk thread without torsion, just capable of supporting it. A sheet of paper properly stretched was interposed; and no sooner was the magnet made to rotate, than the copper commenced revolving in the same direction, at first slowly, but with a velocity gradually and steadily accelerating. The motion of the magnet being reversed, the velocity of the copper was gradually destroyed; it rested for an instant, and then immediately commenced revolving in the opposite direction, and so on alternately. When the poles of the revolving magnet were connected by a piece of soft iron, the rotation of the copper disc was in like manner almost entirely annihilated. The degree in which this development of magnetic virtue takes place in different bodies is as follows: viz. copper, zinc, tin, lead. Silver appears to hold a high rank, and gold a very low one, in the scale of magnetic energy." The experiment may be varied by suspending horizontally by a silken thread, devoid of torsion, a magnetic needle or straight bar magnet, and putting into rapid rotation a metallic disc underneath it; the needle or magnet will deviate from its natural position, and finally assume a rotatory motion corresponding in direction with that of the disc. When the rotation of the disc is reversed, so is also that of the magnetic needle or bar. To show that any currents of air that may be set in motion by the disc do not influence the needle or bar and cause it to rotate, a sheet of glass or paper may be interposed between the disc and magnet, and the effects will be precisely the same. This curious and interesting fact is, we think, even more strikingly exhibited by the apparatus, we believe first constructed by Mr. Sturgeon, and called by him a Magnetometer. It consists of several circular metallic plates, composed of different kinds of metal, each mounted upon a separate axis, and having a weight affixed to its periphery. These plates turn between two metal centres, adjustable by screws, mounted upon a stand, having also two arms or brackets extending sideways from it, at the exterior ends of which is a contrivance for supporting the weight affixed to the circular plate; on reversing the support, the plate is put into a vibratory motion. The weight constantly descending from the same height, and without any propelling power being communicated to it, the metallic plate makes a nearly similar number of vibrations at each time the weight is let free from the support, the number of vibrations being recorded. When a power-

ful compound horse-shoe magnet is so placed that its poles are in a horizontal line, pointing to, and nearly close to the axis of the plate, and the weight is let fall in the manner above described, the number of vibrations will be considerably reduced; as it depends upon the kind of metal of which each disc under experiment is composed.

From what has been said respecting the capacity of metals to acquire magnetical properties by induction or otherwise, it follows that those who construct magnetical instruments for delicate experiments, should avoid the use of metals in the ring or about the needle as much as possible.

Electro-magnetic experiments show the effects of electricity on the magnetic needle, and thereby point out the propriety of not exciting an electrical action by rubbing the glass cover of the compass previous to an observation; for the electricity elicited by the friction will cause a deviation of the needle from its natural position, and consequently interfere with the correctness of the results.

We shall frequently have occasion to allude to the comparative powers of magnetic needles and of magnets, and therefore to give examples of several methods that may be employed for estimating the magnetic intensity of needles and magnets: in the former it is judged of by its directive force, and in the latter by its power of sustaining weights, and also by the deflection produced on a suspended needle when placed in its vicinity in a particular position. To ascertain the magnetic intensity of a needle, suspend it by a few threads of floss silk, remove it 45° from its natural position, and release it in such a manner that no propelling power is communicated to it. Record the number of oscillations which it makes in a determinate space of time before the arc is reduced to ten or any other number of degrees that may be fixed, and it will be found, as in the case of the pendulum, "that the time in which the same magnetic needle oscillates under different degrees of magnetic power, will vary inversely as the square root of that power, or the force will be inversely as the square of the number of oscillations performed in a given time." The needle may be suspended by a very fine wire or twisted silken thread, and the quantity of torsion to cause a determinate deviation from the meridian being noted, the intensity of the needle is pro-

portional to that torsion. The magnetic intensity of large magnets may be estimated by the relative weight of iron they will by their attractive power support, and by the amount of the deviation of a suspended needle (from its original position) which they cause when brought within a fixed distance, and placed in a certain position.

It is known that the magnetic needle in a mariner's compass does not always point in the same direction when placed in different parts of the vessel: this is attributed to the local attraction of the quantity and vicinity of the iron now employed in most ships, and particularly in those of His Majesty's navy.

This iron may possibly become magnetical by induction by the influence of the earth, and thus cause the compass needle to deviate from its natural position. The declination or local attraction varies in the same place, according to the situation of the head of the vessel with respect to the compass, and also with the latitude when the direction of terrestrial magnetism varies.

Mr. Barlow, of the Royal Military Academy at Woolwich, has successfully investigated this subject: and in his excellent and valuable essay on magnetic attractions, has given minute particulars as to the approved method to be employed for determining the local attraction of the iron used in the construction of vessels, and also for arranging and adjusting the apparatus termed "correcting plates," which he has contrived to compensate for that influence.

An easy and simple mode of exhibiting the effects of the local attraction of the ship's iron may be afforded by delicately suspending a magnetic needle upon its centre of gravity, and when reposing in its natural position, placing below one of its poles any mass of iron which may be supposed to represent the iron in the fore part of the vessel; a deflection will then take place at that extremity. Mr. Barlow discovered that an equal effect is produced by a small mass of iron when placed near to a needle, as when a large mass is placed at a distance. To counteract the deflection, if another mass of iron be made to approach the opposite end of the needle, and be arranged above it, the needle will be restored to its original and natural position. It is not necessary that the masses of iron should be equal to each other in bulk (for the reason above stated), as any difference therein may be compensated by bringing the smaller mass closer to the needle, *i. e.* within certain limits; for when iron

is brought *very* near to the magnetic needle, it attracts, whether it be applied above or below, or to the north or south pole; but when at a little distance, the law obtains as described by Mr. Barlow. It must here be observed, that the counteracting mass of iron in a vessel cannot be applied in this manner behind the magnetic needle; as it would in that case be necessary to regulate it for every change of position of the vessel, or of the iron in the fore part. Mr. Barlow therefore recommends, that previous to the vessel's proceeding on her voyage, the amount of deflection caused by the iron should be accurately ascertained. The correcting mass, instead, as in our proposed experiment, of being placed behind and above the needle, should be arranged and adjusted below and before the needle, in a position so as to double the tangent of the angle of deviation. The correcting plates (which are double, and of a circular form, composed of iron about one foot diameter) need not be permanently fixed; for if their exact situation be marked out, they may be removed: and whenever it is desired to estimate the local attraction of the iron in the vessel, they may be replaced, and the number of degrees noticed which they draw the needle from its position; the sum or difference of the angle, as compared with the recorded angle, will be the deflection sought. This operation is to be repeated whenever it may be deemed essential to correct the ship's course in relation to the true magnetic bearing.

Lieut. Johnson, R.N. has communicated some experiments on local and electrical influences on the magnetic needle, in the Journal of Sciences and the Arts. The experiments made by this officer on local influences were tried on compasses variously constructed; and the results proved that they were all similarly, though not proportionally, affected by the iron and steel plates which he used; and appeared to corroborate the theory, that the magnetic virtue and the substance (in this case steel) from which it emanates will sometimes act in unison, and sometimes contrary to each other, on the magnetic needle, according to the bearings and the elevation or depression of the centre of the ferruginous mass from the centre of the needle, as noticed by Mr. Barlow.

M. Poisson, in his clever memoir on the theory of magnetism, has shown how far the experiments which have been made on local attractions can be applied on mathematical principles to the general theory, and also where they cannot.

Magnetism is supposed to accelerate or retard the rate of chronometers; and the rate of these valuable instruments having been found to vary when on shipboard and on shore, the variation has been attributed to the proximity of iron in the vessel. The iron probably becomes magnetical by induction from the earth, and perhaps by inducing an opposite polar state on the steel part of the balance, by attraction accelerates its action, and consequently accelerates the rate. Again, should the steel part of the balance have acquired the same polar state as the iron in approximation with it, by their mutual repulsion the vibrations of the balance may be retarded, it follows as a natural consequence, that the rate of the chronometer is retarded. Hence we see the necessity of preventing if possible the close approximation of masses or surfaces of iron with chronometers on shipboard, and also of forming the arm of the balance of brass instead of steel; a plan adopted, we believe, by most of the superior makers of the present day. It may here be observed, that the smallest inaccuracy in experiments of this nature, may lead to erroneous conclusions as to the effect of certain phænomena on each other.

Soft and malleable iron more speedily acquires magnetism than either cast iron or steel: this, we may fairly infer from some experiments made by Mr. Barlow, is owing to the resistance offered by the hardness of the cast iron and steel (in comparison with that of soft and malleable iron), thereby retarding the impregnation of those bodies by the magnetic fluid. Mr. Barlow ascertained that cast iron and steel, when rendered equally soft with malleable iron, equals if not surpasses the latter in their action on the magnetic needle. To establish this fact he introduced a mass of each, similar in dimensions, into a furnace; and when they arrived at that state of temperature usually designated a blood-red heat, the maximum effect was produced in a very few minutes; and it was observed that cast iron and steel, which at common temperatures were decidedly inferior to malleable iron, when the temperature was elevated so as to render them soft, acted on the magnetic needle with similar energy to that of malleable iron. And further, that iron and steel lose all magnetic power when at a white heat; but when again cooled down to the blood-red heat, their energies on the needle are again restored. The polarity is reversed while the temperature is reduced from the white heat to the blood-red

heat; but when it has arrived at the latter, the phænomenon presented is the same as before. The bars used by Mr. Barlow, when under experiment were all posited in an angle to the horizon coinciding with that of the dip.

A mass of iron when revolving rapidly possesses greater magnetic intensity than when it is in a state of rest. This fact is exhibited by the action of the revolving mass on a magnetic needle which it deflects several degrees from its natural position. Mr. Barlow had a thirteen-inch mortar-shell fixed to the mandril of one of the powerful turning-lathes, worked by the steam-engine at the Royal Arsenal at Woolwich. When the shell revolved at the rate of 640 per minute, the needle was deflected several degrees; it remained stationary while the ball was in motion, but it returned immediately to its original bearings as soon as the motion ceased: on inverting the motion of the ball, the needle was deflected about the same quantity the contrary way; but, as before, it returned to its original bearings when the revolution of the ball ceased. It is remarkable that the effects produced on a magnetic needle by a revolving hollow shell are inferior to those by a solid spherical mass; since it has been verified by experiment, that when reposing their magnetic intensities are equal.

Mr. Christie also devoted his attention to the magnetic action of iron when rotated: he employed plates in his experiments. And he says, "with respect to the direction in which the deviation due to rotation took place, it appears that the rotation of the plate always caused the north end of the needle to move in the same direction as the edge of the plate nearest the south pole and the magnetic sphere; so that the deviation of the north end of the needle was in the direction in which the north edge moved, referring the edges to the poles of the sphere."

Iron becomes magnetic by position when held in the plane of the dip; and a familiar example of this fact may be afforded by suspending a magnetic needle horizontally. If a mass of iron, say a poker for instance, be suspended, and maintained at an angle of 70° to the horizon, and its lower end be applied near to the north end of the needle, the latter is immediately repelled: on the contrary, if the poker be lowered (still retaining the same inclination), and its upper extremity be approached towards the same pole of the needle, instead of being repelled, as in the first instance, it will be

attracted. The same phænomenon is presented when the poker is held in the position described, with its upper extremity brought to the north pole of the needle which is attracted. If now the lower end of the poker be gradually raised, and the same end retained in approximation with the north pole of the needle, it will be observed that when that end which was the lower be made the upper, instead of attraction, repulsion will be the consequence. Hence we see that the lower end is always north, that the poker acquires polarity merely by position, and that that polarity is induced by terrestrial magnetic action.

By hammering a bar of iron or soft steel at the ends or in the middle, magnetic development is elicited, destroyed, or inverted, according to the position in which the bar is held. Captain Scoresby has entered largely into the field of investigation on this subject; and from the result of his experiments, he concludes that the magnetic principle may be more strongly developed in bars submitted to this operation, than can be produced in similar bars treated by any known principle of touching. As the plan the captain adopted is both easy and efficacious, we transcribe that part of his paper published in the Phil. Trans. 1822, relating to the manner he pursued. "The strong magnetizing effects of percussion on soft steel induced me to apply this property to the formation of magnets: for this purpose I procured two bars of soft steel, thirty inches long and an inch broad, also six other flat bars of soft steel, eight inches long and half an inch broad, and a large bar of soft iron. The large steel and iron bars were not, however, absolutely necessary, as common pokers answer the purpose very well; but I was desirous to accelerate the process by the use of substances capable of aiding the development of the magnetical properties in steel: the large iron bar was first hammered in a vertical position; it was then laid on the ground with its acquired south pole towards the south, and upon this end of it the large steel bars were rested while they were hammered; they were also hammered upon each other. On the summit of one of the large steel bars, each of the small bars, held also vertically, was hammered in succession; and in a few minutes they had all acquired considerable lifting powers. Two of the smaller bars, connected by two short pieces of soft iron in the form of a parallelogram, were now rubbed with the other four bars, in the manner of Canton. These were then changed

for two others, and these again for the last two. After treating each pair of bars in this way for a number of times, and changing them whenever the manipulations had been continued for about a minute, the whole of the bars were at length found to be magnetized to saturation; each pair readily lifting above eight ounces."

As neutralizing the effect of terrestrial magnetism on a freely suspended magnetic needle essentially contributes to the exhibition in a more striking manner of feeble electric action upon it, so it may be as well for us to describe the method of accomplishing this desirable object. It is simply as follows. Supposing the needle to be freely suspended upon a pivot, and that it has assumed its place of rest in the magnetic meridian; if we then take a bar magnet and place it in such a position that it is in a line coinciding with the plane of the magnetic meridian, and approaching the south pole of the magnet towards the south pole of the needle, the latter is repelled, and may be continued in any required position, by causing the magnet to recede from, or advance towards, the needle. But there is a certain point, which can only be discovered by experiment, as it depends upon the relative powers of the magnet and of the needle, which completely neutralizes the effect of the terrestrial magnetism, as is seen by the needle placing itself in a plane at right angles to that of the magnetic meridian.

The attractive property of the magnet was known to the ancients, to whom it was only an object of wonder and curiosity; but philosophers of later times have endeavoured to establish a satisfactory hypothesis to account for the phænomena; but little more has been gained by their researches than the discovery of new facts equally inexplicable with those previously known. We have shown that the magnet possesses a directive power, and therefore now proceed to illustrate the action which one magnet exerts upon another; and to give a few examples as to the various methods by which magnetic properties may be communicated to bodies which possess the power of acquiring, and permanently retaining them. Iron, we have observed, may be rendered magnetic by being bent, filed, scoured, hammered, or twisted: we have also shown that it acquires the magnetic property by position and rotation; the magnetic intensity in the former cases being greatly increased by attention to the situation and inclination of the rod of iron when sub-

mitted to those processes, and that the greatest effects are produced when the rod makes an angle of 90° with the magnetic equator, taking the dip at 70°. Perfectly soft and malleable iron or steel receives its entire magnetic development almost instantaneously: but it is evanescent; for on removing the magnet which induced the magnetism, the soft iron or steel no longer manifests magnetic power, and can never be rendered permanently magnetic.

In forming artificial magnets, it is best to make them of steel. Steel is wrought iron changed by cementation with carbon in close vessels, by which it acquires the property of becoming hard on being heated and suddenly cooled by immersion in water. Iron submitted to this process is called blister steel. Blister steel is cut into short pieces, made into bundles, welded together, and drawn into bars, which are again cut into pieces, bundled, and welded together; and thus treated repeatedly, until an homogeneous mass is produced: in this state it is called sheer steel, and is the best for making artificial magnets. Bars intended for magnets ought to be hardened all over, and then tempered to within an inch of each extremity. Sheer steel bears and requires a high degree of heat to harden it, generally termed a cherry-red heat; in other words, a high red heat: and when it has attained this heat, it should instantly be plunged into water, with the bar held in an inclined position according with the dip of the needle. The bar should then be rubbed bright with a piece of gritstone, that the effects of tempering it may be seen, and then be held upon a bar of iron heated red hot, until the blue colour which arises, disappears, excepting one inch at each end, which must be left quite hard. The most approved proportional dimensions of bars for artificial magnets are, that the length should exceed the breadth ten or twelve times, and the thickness be about one third of the breadth.

The method originally practised was to lay the bar to be magnetized in a horizontal position, and to bring into contact with it a loadstone, or the pole of an artificial magnet, and pass it backwards and forwards, pressing moderately; this process being repeated several times on both sides of the bar.

Another plan was to pass the pole of the magnet along the bar, to remove it, and to bring it again to the same end as in the first instance; repeating the operation ten or twelve times on each

surface, when it was found to possess an attractive power as regards iron, but only in a faint degree; and that end on which the stroke commenced, was put in the same state as to polarity with the touching pole of the magnet employed.

A more judicious mode is to proceed as follows. Place the extremities of the bar intended to be magnetized, on the opposite poles of two bar magnets laid longitudinally, with the end intended to be south lying on the north end of one magnet, while the end intended for the north rests on the south end of the other: then uniting the contrary poles of a pair of powerful bar magnets, preserving the same line with the untouched bar, and applying them to the centre of that bar, with the united north pole of the magnets towards the northern end of the magnet on which one end of the bar rests, and the united south pole of the other magnet towards the southern extremity of the magnet on which the contrary end of the bar rests; the distant extremities of the joined magnets forming an acute angle with the bar, and the united poles being separated and moved from the centre along the surface of the bar, the same inclination being preserved until removed from the bar; when, having again brought the poles of the magnets into contact at a distance from the bar, the operation must be continued ten or twelve times on each surface of the bar. On testing the bar under experiment, it will be found to develope considerable magnetic properties; and if composed of steel treated in the manner recommended, it will have become a permanent and determinate magnet. We believe this to be the best method that can be adopted for communicating magnetism to straight bars.

That part of the preceding method which relates to the resting the extremities of the bar under experiment upon the contrary poles of magnets, may be dispensed with, when only small bars or needles are to be magnetized.

Another mode of inducing magnetism on straight bars by contact or touching, is by uniting two bar magnets with their opposite poles in contact, and placing them vertically on the centre of a bar intended for a magnet: if now the lower or touching ends be separated and made to pass with a gentle pressure to and fro a few times on their respective sides of the bar, while the upper ends remain united, magnetic development will be established in the bar. Straight bars may also be magnetized by means of a simple

or compound horseshoe magnet, which should be posited on the centre of the bar and moved to and fro from one extremity to the other; when that end to which the north pole of the magnet was pointed will be south, and the contrary end north.

For many experiments it is desirable to have the assistance of both poles of the magnet at the same time, and that they should not be far removed from each other; for which purpose the bar of steel, before being hardened and tempered, is bent into a horseshoe form, with the arms or branches approached near to each other, and the extremities being made very smooth and even, for receiving a piece of soft iron usually designated a lifter or feeder.

The sustaining power of magnets of this construction greatly depends upon the distance the poles are separated from each other, and the perfection of the contact between the poles and the lifter.

There are several methods which may be employed with advantage for impregnating the horseshoe-formed steel bars with the magnetic principle. Place two strong bar magnets longitudinally, with their opposite poles united to the branches or arms of the horseshoe-formed steel bar, and connect the distant poles of the bar magnets by means of a piece of soft iron, or another magnet: when the upper surface of the horseshoe-shaped bar is passed over by a horseshoe magnet, care being taken that that pole of the uniting bar magnet be opposed by a contrary pole of the exciting horseshoe magnet, at the same time a contact of the poles of the bar and horseshoe magnet being prevented; and this operation being continued many times, the horseshoe-formed bar acted upon becomes a durable magnet.

If two bars bent into the horseshoe form, with the end of one marked for north opposed to the unmarked or intended south end of the other, be united, and a strong compound horseshoe magnet be moved over the arrangement with a slight pressure, and the north pole of the exciting or touching horseshoe magnet be in the same direction with the designed south pole of one of the arms of the proposed magnets, and the movement be continued circularly about a dozen times,—a piece of soft iron being placed as a lifter on the extremities of each of the horseshoe bars; upon disuniting the arrangement, the bent bars submitted to this process will have had considerable magnetic power imparted to them: should the appli-

cation of the lifters be neglected before the separation, the horseshoe bars will be found to have lost a great deal of their power.

A superior method to any yet described, is afforded by laying the horseshoe-formed steel bar horizontally; place at its extremities a piece of soft iron, slide a powerful compound horseshoe magnet gently off its feeder or lifter on to one branch or arm of the bar, with its marked end in the same direction with the unmarked arm of the intended magnet; then move the compound magnet from the extremity of one arm to the extremity of the other arm about twelve times, concluding at the bent part of the bar; turn the magnet one quarter round, and bring its marked pole over the unmarked pole of the horseshoe bar towards the piece of soft iron which unites its extremities, pass it over that, to its own lifter or feeder placed ready to receive it. Great care must be taken in removing the exciting magnet, that the piece of soft iron attached to the ends of the arms of the horseshoe bar is not removed by the magnet as it passes on to its own feeder; for if contact be not preserved between them at this point of the experiment, little power will have been gained by the bar.

In all cases where magnetism has been communicated by contact or touching, if the exciting magnet be passed over but once in a contrary direction to that in which it moved in exciting magnetism, the whole effect will be destroyed, and the bars will upon trial be found in nearly the state they were before being subjected to the process.

The compound horseshoe magnet is constructed by combining several of the bent magnets before described, so as to form one instrument,with all the marked ends on the same side: they are usually bound together by three screws or rivets; and considerable accession of power is said to be obtained, by interposing between each bar a thin plate of lead or zinc. The augmentation of power obtained by the combination of several bent magnets depends greatly on the lengths of the magnets, also on the manner in which the poles are made to range with each other. The weight which the compound horseshoe magnet will support by its lifter or feeder, is the usual test for estimating its strength. Regard should be paid to finishing the ends of the branches or poles: their surfaces should be ground perfectly smooth and even with fine emery and oil, as should also that of the lifter or feeder; as the sustaining

power is greatly assisted by the perfection of the surfaces in contact.

In this brief description of a science of such paramount importance as magnetism necessarily becomes to a maritime people, an effort has been made to give the reader not previously acquainted with the science, a sufficient knowledge of its principles to enable him to understand the peculiar phænomena treated of in the following section on Electro-magnetism; and by the terms there employed, the observations here made, as well as those on the science of electricity, he may obtain a distinct idea of that singular class of experiments which present such interesting matter for the consideration of the philosophical inquirer.

We shall conclude our remarks on magnetism, by enumerating a few among the many hypotheses founded on the phænomena of the science; contenting ourselves, however, with simply laying them before the reader, and leaving the question of pre-eminence exclusively to his judgement.

The facts of this science were first attempted to be explained on philosophical principles by M. Æpinus; and his theory therefore has the prior claim to attention. M. Æpinus supposes that a principle resides in all bodies susceptible of magnetism, analogous in its effects to a fluid, the particles of which repel each other with a force decreasing as the distance increases; and that these principles have an attractive quality for, and are attracted by, particles of ferruginous matter, with a force that varies in accordance with the same law; and that particles of iron act upon each other with a repulsive force in obedience also to the same law. He supposes that what he calls the magnetic fluid, passes freely through the pores of iron and soft steel; but that its progress becomes obstructed in proportion to the hardness of the metal.

Mr. Barlow concludes that two magnetic fluids exist in opposite states, the particles of which are united in different quantities, the similar fluid repelling, and the dissimilar fluid attracting each other; both remaining latent in a metallic body until called into action by some exciting cause. If a magnetized body, or one in which the equilibrium of the two fluids has been disturbed, be approached to a mass of soft iron in which the fluids are in an undisturbed or latent state, the concentrative action of the fluids of contrary power in the magnetized body acting on the fluids of an op-

posite kind in the latent body, will cause that body to exhibit magnetic properties, continuing as long only as the two bodies remain in contact; the quantity of magnetism developed by the mass of iron being dependent on its condition in relation to the quantity of the two fluids it possesses, thereby regulating its capacity for the development of magnetic action; on the texture of the metal, the cohesive nature of which controuls the depth whence the exciting magnet separates the two fluids. In the instance of hollow spheres of iron in a temporary magnetic state, by the action of terrestrial magnetism, Mr. Barlow conceives the effect to be produced by every particle of the sphere being acted upon in parallel lines, coinciding with the direction of the dip; and that the exciting cause acts with equal force, its centre being equidistant from each particle of the sphere, causing equal disturbance in those particles.

M. Hanstein, professor of astronomy at Christiana, from the result of numerous experiments on terrestrial magnetism, is led to conclude "that the earth has four magnetic poles, which belong to two magnetic axes, forming angles of from 28° to 30° with the axis of the earth. The arctic pole of one of the axes he places very near Hudson's Bay, and its southern pole in the Indian Ocean, below New Holland. The arctic pole of the other is to the north of Siberia, near Nova Zembla, and its south pole in the great South Sea, a little to the east of Terra del Fuego. These magnetic axes are supposed to change their position every year, and thus to cause the variation observed in our instruments.

The existence of four magnetic poles was entertained by Dr. Halley, who considered the earth to be a hollow sphere, containing a solid spherical mass, both having a common centre and axis of diurnal rotation, consequently both performing nearly equal revolutions; and further, that the solid mass possessed two magnetic poles, as did also the hollow sphere, and that the change of the variation observed in the compass needle was effected by the rotations of the hollow sphere and solid mass being unequal.

M. Ampere supposes that the line which unites the opposite poles of the magnet is surrounded with electrical currents, placed in planes perpendicular to the axis; so that these currents, and not the longitudinal magnetic distribution, are the cause of magnetism.

M. Poisson, in memoirs read before the Academy of Sciences at

Paris, February and December 1824, which are translated and published in the Quarterly Journal of Science and the Arts, Nos. XXXIII. and XXXIX., has proposed a theory on magnetism, well worthy the attentive perusal of all those who are interested on this particular subject; and we regret our confined space will not admit of our entering upon the views of this eminent philosopher.

ELECTRO-MAGNETISM, OR ELECTRO-DYNAMICS.

ABOUT the close of the last, and beginning of the present century, attempts were made to establish an identity or intimate relation between electric and magnetic fluids; and M. Ritter asserted that "a needle composed of silver and zinc arranged itself in the magnetic meridian, was slightly attracted and repelled by the poles of a magnet; and that a metallic wire, after being exposed in the voltaic circuit, took a direction N.E. and S.E." These experiments attracted but little attention at the time, probably from the vague and loose manner in which M. Ritter expressed his ideas; but he certainly appears to have had some obscure notion that an electric stream conferred magnetic properties on a wire while passing through it, and also that magnetism might be induced on metals not composed of ferruginous matter by the action of voltaic electricity.

No satisfactory results were obtained until M. Oersted, professor of natural philosophy, and secretary to the Royal Society of Copenhagen, in the autumn of 1819 made a discovery, which when published attracted the attention of philosophers in all countries. He found, that when a magnetic needle was brought towards a wire through which a current of electricity was flowing, the latter had the power of attracting and repelling it in a constant manner, and in obedience to a defined law. These facts formed the basis of that novel branch of physics termed Electro-magnetism by M. Oersted; as he imagined that it was essential to the development

of the facts of the science, that a magnetic needle should be one of the elements. The French philosophers remarked, that the magnetic needle might be dispensed with, and its place occupied by a second conductor. They found that two conductors influenced each other, and exhibited similar magnetical attractions and repulsions, as did one conductor and a magnetic needle: and they therefore preferred the term Electro-dynamics. As neither appellation is applicable in all cases, we deem it right to retain the name given to the science by its discoverer; it is the one more generally used, and is also that which is adopted in our own country.

Professor Oersted observed, that if a magnetic needle freely suspended and at rest in its natural position were opposed to a straight portion of a connecting wire placed horizontally above it and in the same direction, while electricity passed along the wire, that part of the needle nearest the minus extremity of the combination deflected towards the west. If the connecting wire were carried under the needle, similar effects were produced; but the deflection was in the opposite direction; the pole of the magnetic needle near the minus part of the battery then declining to the eastward.

If the straight portion of the connecting wire be ranged in the same horizontal plane with the needle when brought near to it, the needle has no motion in that plane, but has a tendency to assume a position in a vertical circle; but it is prevented from so doing by the manner in which it is suspended, and terrestrial magnetic action. When we place the connecting wire on that side of the needle which is towards the east, the pole of the needle in the same direction with the minus end of the battery attempts to ascend; but if the connecting wire be placed on the opposite side of the needle towards the west, the pole of the needle, which before attempted to ascend, makes an effort to descend.

If, when the magnetic needle is at rest in its natural position, a connecting wire be placed at right angles *below* it, when the plus electric stream flows from that extremity of the connecting wire which is towards the east, the needle remains in a quiescent state; but when the plus electric stream flows from the western extremity of the wire, the needle is acted upon and performs half a revolution, presenting its south pole to the north pole of the earth. If the connecting wire be now ranged *above* the needle, and the

same relation as regards position be preserved, the plus current from east to west, electro-magnetic phænomena are again exhibited by the deflection of the magnetic needle, which turns half way round, and points its south pole to the northern quarter; but if the plus current flows from west to east, it leaves the magnetic needle unmoved.

When the connecting wire and needle are at right angles, on passing the wire along the needle towards either pole, the end traversed by the wire will be strongly attracted by it. If the wire is over either pole of the needle, and that pole is attracted by it, on the contrary pole being brought round and approached to the wire, it will be repelled: the same effect is produced on both poles, the wire repelling the contrary pole to that which it attracts in the first instance; the same point of the wire attracting and repelling both poles of the needle according to circumstances. The attractive power of the wire for the pole of the needle seems strongest when the wire is just over the extremity of the needle: little or no action is perceivable when it is opposed directly to the extremity; but when passed just under the extremity of the needle, repulsion is the consequence, and its intensity is in the same ratio as the attraction. The magnetic needle is effected by a voltaic combination in the same manner as by the uniting wires.

The wire employed for uniting the extremities of the voltaic combination may be composed of any metal, and the effects will be nearly the same; but the electric current appears only to act forcibly on magnetic bodies; for it is found that when needles composed of all the metals, (even iron in an unmagnetized state,) glass, and gum-lac, and placed within the influence of the hydro-electric current, that no electro-magnetic phænomena are exhibited. Hence it is inferred, that the remarkable effects before described can be produced on magnetic needles only, the amount of the acting force being proportionate to the size and activity of the battery employed. Scarcely any diminution of effect is perceptible when plates of glass or any other non-conducting medium are interposed between the uniting wire and the magnetic needle.

To retain an accurate notion of the relative position of the electrified wire with the deflected magnetic needle, we have only to remember, that, on looking along a wire from that end in

which the minus electricity enters, the pole of the needle pointing to the north, when the current passes *above* the needle, it will be deflected to the east; and that when the electric current passes along the wire placed *below* the needle, in a similar manner, the pole, which in the former case was deflected to the east, will assume a westerly direction; if we suppose our body to form part of the conducting wire with the front side facing the needle, and the minus electricity flowing upwards from the feet, the deflection will in all cases be to the right hand. The electro-dynamic force of a conducting wire is constant for all points of the wire.

Many of the greatest discoveries in philosophy have been the result of fortuitous circumstances;—not so that of electro-magnetism: for Professor Oersted, to whom the science itself owes its birth, anticipated its discovery several years before the facts were developed; and in 1806 or 1807, when pursuing his inquiries into the nature of chemical, electrical, and magnetic forces, he arrived at the conclusion, that the propagation of electricity (we use his own words) consisted in a continual destruction and renewal of equilibrium, and thus possessed great activity, which could only be explained by considering it as an uniform current. He then considered the transmission of electricity as an electric conflict; and his researches into the nature of heat, produced by electrical discharges, led him to the inference that the two opposite electrical forces which pervade a body heated by their effects, are so blended as to escape observation, without, however, having acquired perfect equilibrium; so that it was probable they might still exhibit great activity, although under a form differing entirely from that which may be properly termed electrical; and as *light* and *heat* were both given out by an electrical discharge, it occurred to him that so also might *magnetism;* and that in voltaic electricity, the force was more latent than in ordinary electricity; and still more so in magnetism than in voltaic electricity. This caused him to put this question, Does electricity in its latent state affect the magnetic needle?

It has been shown that a most satisfactory answer was subsequently given by the Professor himself. And from observations made in the first paper he published on the subject, we may collect that he supposed the electric conflict (as he termed it) resisted the magnetic fluid only; and that all bodies not possessed

of magnetic properties allowed the electricity to penetrate them, and that no contending effects were perceived; that the magnetic needle had a tendency to describe a circle round the connecting wire, and the quantity of declination given to the needle from the electrified wire varied with the size of the battery. In the second publication of Professor Oersted, he more distinctly states his views of the rule by which all electro-magnetic effects are governed. It is this: "When opposite electrical powers meet under circumstances which offer resistance, they are subjected to a new form of action; and in this state they act upon the magnetic needle in such a manner, that positive electricity repels the south, and attracts the north pole of the magnetic needle; and negative electricity repels the north, and attracts the south pole; but the direction followed by the electrical powers in this state is not a right line, but a spiral one, turning from the left hand to the right." In another part he says, that the magnetic effects do not seem to depend upon the *intensity* of the electric fluid, but solely on its *quantity*; and also that he had constructed a voltaic combination so light, that being suspended it moved on the approach of a magnet.

On repeating the experiments of Professor Oersted, it will be found that the terrestrial magnetism is complicated with that of the electrified wire. This difficulty may be overcome by placing in the vicinity of the needle a magnet so disposed, as nearly to counteract the terrestrial magnetic influence, or by employing an astatic needle: by these means we are enabled to overcome the directive force, and consequently produce greater effects on the needle. It will be observed in all cases when an electrified wire is presented horizontally above, below, or at the sides of a magnetic needle that has freedom of motion, that the latter has a tendency to range itself at right angles to the current of electricity transmitted by the wire; and that when a magnet is approached to an electrified wire free to move, it has an inclination to place itself at right angles to the magnet.

Although the electrified wire exerts such a decided influence on the magnetic needle, as is demonstrated by the preceding experiments; yet when a powerful magnet is applied to a conducting wire connected with a multiplier or galvanascope, that no increased or decreased effects are perceivable; from which circumstance we should infer that the magnet, when presented to the conducting

wire, has no disposition to accelerate or retard the passage of the electric current along that wire.

Sir H. Davy and M. Arago, about the same time, showed that a connecting wire possessed magnetic properties while the electric current flowed through it; for on presenting to a wire (of any kind of metal), placed in the voltaic circuit, some iron filings, they were immediately attracted, and adhered to it; but on breaking the communication, they instantly dropped off, proving the magnetic effect to be due solely to the electric stream which passed along the wire.

Both these philosophers found that the electric current induced permanent magnetism on steel bars placed within its influence; that contact of the steel bars was not necessary, and that the maximum effect was produced instantaneously by the mere juxtaposition of the needle in a transverse direction to the straight connecting wire, even when plates of glass were interposed. Sir H. Davy "arranged a number of steel needles as polygons in different circles round the same piece of pasteboard, the needles being made magnetic by electricity; and it was found that in all of them,—whatever was the direction of the pasteboard, whether horizontal or perpendicular, or inclined to the horizon; and whatever was the direction of the wire with respect to the magnetic meridian,—the same law prevailed." Hence he imagined, that as many polar arrangements may be formed as chords can be drawn in circles surrounding the wire; and the phænomena so far agreed with an idea suggested by Dr. Wollaston, who supposed that a kind of revolution of magnetism existed round the axis of the wire, and that its direction depended upon the position of the plus and minus extremities of the electrical apparatus.

Sir H. Davy, having observed that the intensity of the magnetism, induced by the influence of an electric current on steel needles was proportional to the quantity of the electricity transmitted through the wires,—conceived that similar effects might be produced by placing small needles transversely to a wire in communication with a Leyden battery: and upon discharging the battery through the wire, the needles placed transversely were found to have received permanent magnetism; the same law prevailing in ordinary electricity as in the electricity elicited by the voltaic combination. The needle *below* the wire, the plus conductor being to

the right hand, that end towards the operator acquired north polarity: when the needle was placed *above* the wire, and the same conditions preserved as to the relative position of the wire and the operator, that end towards the latter developed south polarity.

Imperfectly conducting liquids do not give polarity to steel when electricity is passed through them; but electricity transmitted through air produces that effect. When a powerful magnet is presented to an arc, or column of electrical light, flowing from one connecting wire to another of a very extensive series of voltaic batteries in a state of high activity, the arc or column is attracted or repelled with a rotatory motion, or is made to revolve by placing the pole in different positions.

The direction of magnetic polarity acquired by small needles exposed to the influence of an electric current transmitted along a straight wire, differs with the distance of the wire. The magnetic polarity induced on a small needle by the electrified wire at a particular distance, is removed when the needle is withdrawn to another particular distance, again restored when the needle is removed a little further, but the polarity is reversed: when the needle is made to recede to another certain distance, the magnetism is again destroyed; and the poles of the needle are in a similar direction as when the magnetic property was first induced upon it; the distance at which the zero and the maximum of magnetism take place, vary with the length and diameter of the wire, and with the intensity of the electricity.

To induce permanent magnetism on steel needles, the best method is to coil a copper wire round a glass tube, and connect the ends of the wire with the zinc and copper plates of the voltaic battery: if now a small sewing needle, previously ascertained not to be magnetical, be inserted into the glass tube, on the transmission of the electric stream along the helical coil, the needle will immediately be magnetized. When the tube is supported in either a vertical or horizontal position, and a very powerful battery employed, the needle will be suspended in the helix as an axis, the suspending power of the electric current overcoming that of gravity. When it is intended merely to magnetize a needle, it should not be allowed to remain in the helix, but removed immediately, as the maximum effects are produced instantaneously; if the needle be left but a few minutes, the polarity originally acquired by it will be changed, if not entirely destroyed.

The needle to be magnetized, if it be not very hard, need not have its whole length inserted into the glass tube; for if held in the hand so that only half is within the helix, it will acquire the magnetic virtue equally with one that has been wholly acted upon, for the portion of the needle which has received the magnetism communicates it to the other portion. When a small part of a needle very highly tempered is introduced into the glass tube, and its acquired magnetism tested by a suspended needle, the virtue will be found extended to about double the length of the part that was inclosed in the glass tube.

Some very singular appearances are presented when on introducing part of the connecting wire, formed into a flat spiral, with the rings not continued to the centre, among some iron filings; and the spiral is laid flat upon the pile, the attracted particles of the iron arrange themselves in lines moving through the ring parallel to the axis, and then close up as radii round the edge. The particles of iron in the centre of the helix erect themselves in a perpendicular filament, and represent the axis of the helix, while the interposed particles form filaments inclining from the centre in proportion to their distance from it.

We are indebted to M. Ampère for the discovery of the action which two electrified connecting wires, forming a closed circuit, exert on each other. He remarked, that when two connecting wires were parallel, with their currents flowing in the same direction through them, they were attracted towards each other; and when the currents passed in opposite directions through the wires, they were mutually repelled; the repulsion between the two currents being equal to the attraction exerted by the same currents.

The opposite sides of a connecting wire, when the circuit is closed, are in different polar states, the one side attracting the north pole of the magnetic needle, and repelling the south; the contrary side attracting the south pole, and repelling the north.

If we conceive, as Dr. Wollaston has done, that this magnetism is vertiginous, and due to the current moving round the axis of the connecting wire; and that two powers exist in the wire at its opposite sides, or that each power continues all round the wire, in the same direction,—it may be inferred that the reciprocal action exerted by the two connecting wires are not simple, but compound actions.

Similar phænomena present themselves when we employ one connecting wire and an artificial magnet, as when we use two connecting wires; but polarity resides on the opposite *sides* of the electrified wire, while in the artificial magnet it is developed at the *ends*.

If one of the connecting wires be fixed, and the other has free motion with the currents passing along them in opposite directions, that wire which is free, turns round and ranges itself in a position, so that the currents flow in the same direction. These phænomena are curious, as marking a distinction between the attractions and repulsions of a complete circuit, and those of the circuit that is incomplete. For instance, in the case of electrical attractions and repulsions, the former happens when dissimilar electricities are opposed, and the latter when similar electricities are opposed: but it appears in the completed circuit the order of things are reversed; for similar ends attract, and dissimilar ends repel.

The effect presented by the two connecting wires may justly be termed magnetical; for when the two wires are attracted towards each other and touch, they remain in contact; whereas, on the contrary, when two substances electrified by ordinary electricity are made to approach each other, after their union they repel each other.

The theory which M. Ampere formed to account for the singular magnetic property of an electrified wire, was, "what we have hitherto been accustomed to consider; as magnetic fluids or forces, in a natural or artificial magnet, consist merely of electric currents, always revolving about every particle of such a body in planes perpendicular to its axis; so that the attraction or repulsion that takes place between the opposite poles of two magnets is merely the attraction of these electric currents; and in the same way the direction, which a magnetic needle assumes when under the influence of an electrified wire, proceeds from the attraction between the wire and the parallel currents in the magnets when these correspond in direction, or from the repulsion between them when the currents are in opposite directions; and in like manner, the direction which a needle assumes from the terrestrial action, is not, as had been hitherto supposed, due to magnetic poles in particular situations in the earth, but to the attraction of electric cur-

rents circulating about the earth in circles nearly parallel to the equator."

We cannot produce a continued rotatory motion in a constant direction upon either of two connecting wires by the reciprocal action of the two or of more wires, however we may range them. The greatest effects that can be produced on frames composed of the connecting wires, is to place that frame which has freedom of motion round its axis in an assigned position. If a magnet be so arranged that it can move only round its axis, and if we conceive that the magnetic virtue which it possesses is due to electric currents, no rotatory motion ought to be given to it by the action of other magnets, which is really the case. It follows therefore, that if the electro-dynamic theory of M. Ampere were correct, a magnet could not be made to revolve on its axis by the action of an electric current. Two closed circuits cannot produce that effect, nor can two magnets. Supposing with M. Ampere, that the magnet derives its properties from electrical currents, the action of a closed circuit and a magnet would be analogous with that of two circuits or two magnets; and it is probable that it is so. An apparent anomaly seems to exist in the instance of the magnet rotating on its axis, when the electric circuit and magnet are both employed: yet it must be remembered that the magnet itself forms part of the circuit; and in that case there may be rotation. We have noticed these facts particularly, as they have been thought important as tending to establish the electro-dynamic theory.

Magnetism may be induced on steel needles placed transversely to a straight wire transmitting the electric current; but an increased magnetic power is conferred on the needle when the connecting wire is formed into a helix, and the needle placed within it, in consequence of the arrangement of the wire presenting such an extended surface to the needle, which is necessarily acted upon by an augmented force. The superior power possessed by a helix over the straight wire may be accounted for (if we conceive the direction of the magnetic power to be perpendicular to the conducting wire,) in this way: "When the conducting wire is parallel to the axis of a helix, the power is perpendicular to that axis: if the wire form a circle round the axis, in a plane perpendicular to it, the power is in the direction of the axis: but when, as in the helix, it passes round the axis, in a direction intermediate

between parallelism and perpendicularity, the direction of the power is of course inclined accordingly. In this case the power may be considered as composed of two portions, one perpendicular to the axis, the other parallel to it."

When a steel needle is placed within a helical coil of wire, along which an electric current is passing, if glass or any nonconducting substance be interposed between the wire and the needle, no diminution of effect is observable. The quantity of magnetic virtue communicated to the needle is in proportion to the *quantity* of the influencing electric current, and the ratio between the length and dimension of the wire forming the helix.

The poles of a steel needle submitted to the action of an electric current transmitted through a helix, depend upon the direction in which the wire composing the helix is coiled. If the coil passes from the right hand downwards towards the left above the axis, that end of the needle near to the plus end of the battery becomes the true north pole, and consequently points south; when the coil proceeds from the left hand downwards towards the right above the axis, then that end of the needle near to the plus end of the battery acquires true south polarity, and necessarily points north.

The situation and number of magnetic poles induced on a steel bar may be altered, increased or decreased, at pleasure, by employing differently formed helices, singly or conjointly, and varying their order of succession.

The artificial magnet may be imitated by forming a wire into a helix, and returning the two ends of the wire through the helix till they approach the centre, whence they must pass to the outside, one bent upwards and the other downwards: when an electric current flows through this arrangement, it acquires polarity similar to a real magnet, the one end attracting that pole of the magnet which the other end of the helix repels, and *vice versâ*. The polarity of the helix may be inverted by changing the direction of the electric current.

If a helix be formed round a cylinder of soft iron, and an electric current passed along the helix, the cylinder becomes a temporary magnet, its power depending upon the size and state of activity of the exciting combination. The cylinder may be made to rotate in the same manner as the artificial magnet, and the direction of rotation varied by changing the direction of the current.

Some French philosophers, who considered that the principle termed magnetism was due to electric currents, were led to hope that a combination might be arranged composed of magnets and wires, so as to effect the decomposition of water, and produce other electrical effects; arguing, that as electricity caused magnetism, magnetism ought to cause electricity. Various ingenious apparatus were constructed by the philosophers interested in this particular subject, and at one time great hopes were entertained that success had crowned their labours; but subsequently it was announced that the appearances were fallacious, and not such as would authorize the conclusion that any certain effect had been obtained.

We are indebted to M. Ampere for an apparatus which distinctly shows that a freely suspended electrified wire is influenced by terrestrial magnetic action, and that it possesses a directive force as well as a magnetic power. The wire was bent so as to form a circular frame nearly closed, on the communication being made with the battery; so that the current was transmitted along the wire, which, being freely and delicately suspended, was observed to arrange itself in a plane perpendicular to the magnetic meridian. Several forms of wire may be used for showing the directive property of a freely suspended electrified wire; but the flat spiral affords the best arrangement of the wire, presenting precisely analogous effects with those of a circular or rectangular form, is more sensible of the earth's magnetism, and more readily managed.

A clever little instrument, which very strikingly illustrates the phænomena of the directive quality and magnetic property of an electrified wire, was invented by M. de la Rive of Geneva; it consists of a small voltaic combination, similar to that suggested by Dr. Wollaston. A piece of copper wire covered with silken thread is coiled a few times, and tied together so as to form a ring or closed helix; the extremities of the wire are connected with the zinc and copper plates, sustained in a light glass cylindrical vessel affixed to a piece of cork, so that the whole may be floated on water. When the electricity is excited by the action of a dilute acid solution on the plates, and the apparatus is floating, the ring will range itself in a plane perpendicular to the magnetic meridian, in consequence of the influence of terrestrial

magnetism on the connecting wire. The ring is also very obedient to the magnet; for when a bar magnet is held horizontally, and presented to it in a line coinciding with the axis of the ring, the latter is found to possess the properties of a magnet, attracting and repelling either pole of the magnet. If that side of the ring be towards the pole of the magnet which mutually attract each other, the ring advances slowly until it envelopes the pole of the magnet; its motion then quickens, and it proceeds with increased velocity to the equator or centre of the magnet: on withdrawing the pole from the ring, and inserting the opposite pole, the ring recedes until it gets off the magnet, when it turns itself round, presenting its opposite side to the magnet; and instantly approaching it, rushes forwards until it has again arrived at its equator, where it remains stationary as before. When a magnet is supported over the ring, and a pole approached to it, the ring ranges itself in a plane perpendicular to the magnet, but in a contrary direction to the former one.

The converse experiment is exhibited by coiling a copper wire round a glass tube, about an inch in diameter, and arranging it horizontally in a vessel containing water, so that the upper surface of the fluid coincides with the axis of the glass tube : if a small magnetized needle be floated, and the electric current transmitted through the helical wire, the needle is strikingly affected, and places itself opposite one extremity of the wire, parallel to the axis of the tube; then advancing with considerable velocity it enters the tube, moving through it to nearly the contrary end, again returns to the end it first entered, and remains at rest in the centre of the tube parallel to the axis, supported and retained apparently by the equal attractions of the currents which pervade the helical wire. Similar effects are produced at either end of the helix, but by contrary poles; but if a different formed helix be employed, then the reversed poles will first enter the tube, which will be the case also if we change the direction of the current along the wire.

If a needle be placed in the glass tube with its poles in a direction opposite to that which they would be were the needle allowed to adjust itself;—thus when the electric current is passed along the wire, the needle will be ejected at that end of the tube to which it may be nearest,—it is necessary that this part of the experiment should be rapidly made, otherwise the magnetizing power

possessed by the helix will reverse the poles of the needle. If the glass tube be supported vertically, partly in the water, the needle will be agitated as before described, diving and remaining below as long as the connection with the battery is retained.

These singular experiments were originally performed by Mr. Faraday, to determine if the electrified helix was identical with an artificial magnet,—an assimilation which had been made by M. Ampere: and they certainly tend to the conclusion that no such identity exists; for if a needle be presented to the extremity of a hollow cylindrical magnet, it has no tendency to enter the tube, but is attracted by the nearest extremity of the edge. If a light wire be coiled as a helix on a hollow reed, and the ends returned through the reed till they approach the centre, and passed to the outside between the coils, and their extremities connected with the zinc and copper plates of a small voltaic combination,—the other parts of the apparatus being similar to that of M. de la Rive's,—the current of electricity passes along the wire from one extremity of the helix to the other, and returns through the centre to the plates. When excited and floated, the helix will assume a polar arrangement, and its extremities will indicate opposite magnetical states, being attracted or repelled by either poles of a magnet.

The first example of rotatory motion produced by electro-magnetism was the happy contrivance of Mr. Faraday, who, when repeating the experiments of M. Oersted, observed that the effect produced on the magnetic needle by the electrified wire was considerably modified by its relative position. And he says, "that if the wire be made to approach perpendicularly towards one pole of the needle, the pole will pass off on one side in that direction which the attraction and repulsion at the extreme point of the pole would give; but if the wire be continually made to approach the centre of motion, by either the one or the other side of the needle, the tendency to move in the former direction diminishes: it then becomes null, and the needle is quite indifferent to the wire; and ultimately the motion is reversed, and the needle powerfully endeavours to pass the opposite way." And reasoning on these facts, he drew the important inference, that the true pole of the magnet was not at its extremity, but in its axis, a little remote from it, towards the centre; that this pole has an inclination to rotate about

the electrified wire, and consequently the electrified wire to rotate about the pole of the magnet; and that as there existed no real attraction between the wire and either pole of the magnet, that the wire ought to rotate about the magnetic pole, and the magnetic pole about the wire.

It is not necessary that we should here describe the ingenious apparatus which Mr. Faraday constructed to obtain the results he anticipated. We shall content ourselves by merely stating that he succeeded; and when the magnet was brought to the centre of motion of a freely suspended wire, and a current was flowing through the wire, it immediately acquired rotatory motion, the course of the rotation depending upon the course of the current; or in other words, the course of rotation was influenced by the plus electricity flowing up or down the wire. The rotation was reversed also by reversing the pole of the magnet. When the magnetic pole was ranged outside the wire, instead of inside as in the former instance, the wire had the same tendency to rotate about the pole as a centre.

The revolution of the magnetic pole about the electrified wire was produced by fixing the wire and giving freedom of motion to the magnet. When an electric current was transmitted through the wire, the magnet commenced a rotatory movement about the electrified wire; the direction of rotation depending on the magnetic pole opposed to the wire, and to the direction of the electrical current through the wire. By these apparatus rotatory motion was exhibited by a force hitherto unknown in mechanical philosophy.

The revolution of the wire about the magnetic pole, and the magnetic pole about the wire, may be shown at the same time and by the same wire and magnet. If the apparatus be so arranged that both wire and magnet have freedom of motion; when the electric current flows through the wire, it revolves about the magnetic pole, and the magnetic pole about the wire.

To account for the rotation of the electrified wire about the magnetic pole, and the magnetic pole about the wire, on the theory of Dr. Wollaston, we must suppose that in a helix the vertiginous magnetism of one species on one side of the wire is collected in the axis, and the opposite kind diffused; therefore that one side of the wire has considerable power, whilst the other is almost inert:

and if we examine a helix, we shall find the power of each of its sides concentrated at its end, and that these ends assimilate with the poles of a magnet. The opposite sides of a wire have similar properties with the poles of a magnet; and when the latter is brought near to the electrified wire, it assumes a rotatory motion by the double action of the wire; first moving in the direction of that side which attracts it, and receding from that side which repels it, the attracting and repelling powers being equal; and from contrary sides the magnetic pole revolves in a circle by the joint action of the attractive and repulsive forces of the wire.

In the rotation of the electrified wire, each point of the wire moves round in a plane perpendicular to the electric current of the wire. If we experiment with terrestrial magnetism, and assume that the line of the dip, if not directed to the true pole of the earth, marks out that part in which the magnetism is most active, it will be apparent that a straight electrified wire, when acted on by the terrestrial magnetic pole, would have a tendency to move laterally at right angles to the dipping needle: in other words, that the wire is disposed to describe a circle about the pole, a line coinciding with the needle extending to the pole representing its radius. It follows that this circle must necessarily be of immense magnitude, and therefore but little of it within the reach of experiment; yet that portion, although very minute, is enough to exhibit the effect; for as the motion is equal in every part, so that part under observation must be of the same kind.

Entertaining these views, Mr. Faraday inferred, that an electrified wire would move sideways, in a plane perpendicular to the dip, by the action of the terrestrial pole; and taking the angle of inclination as 70° 03′, that plane would consequently form an angle of 19° 57′ with the horizon: but he considered that the difference between that plane and the horizontal plane would not interfere with the results he anticipated, and that he should obtain motion by employing the latter. Motion he did obtain, by bending the extremities of a piece of light wire into right angles in the same direction, and suspending it by a silken thread in equilibrium, the points of the bent ends dipping into mercury. On arranging the connecting wires so that the current was transmitted through the bent wire, it was immediately projected laterally: on breaking the connection with the battery, it resumed its original position; the

direction in which the wire was projected was changed by reversing the order of direction of the current.

As no artificial magnet was here employed, we may fairly conclude that the motion of the wire was caused by terrestrial magnetic influence, and that the wire had a disposition to describe a circle round the pole of the earth. This conclusion is strengthened by noticing the increased effects produced by supporting a bar magnet in the line of the dip, with its south pole under the vessel containing the mercury; for in our latitude the terrestrial magnetism is of a similar nature with that pole of the magnet usually designated south.

Mr. Faraday noticed in his experiments of the rotation of an electrified wire about the pole of the magnet, that a very limited portion was perpendicular to the wire; and he suspected that if he delicately suspended an electrified wire, it would rotate about the line of the dip by terrestrial magnetic action. The rotatory motion was strikingly exhibited by ranging a very light wire delicately suspended by one of its ends in such a manner as to have free motion in an angle 40° with the horizon; the other or lower end having a piece of cork affixed to float it on mercury, into which the extremity of the wire dipped. When the electric current was passed along the wire, and the circuit complete, the wire assumed a rotatory motion, the course of the rotation according with that which would have been produced by the south pole of the magnet. When the light wire was in an angle coinciding with the dip, there was no motion; and when the angle was increased beyond that of the dip, the wire was propelled in two different directions, as it was placed to the north or south.

From these and other ingenious experiments instituted by Mr. Faraday, he concludes, "that in every part of the terrestrial globe an electro-magnetic wire, if left to the free action of terrestrial magnetism, will move in a plane (for so the small part we can experiment on may be considered) perpendicular to the dip of the needle, and in a direction perpendicular to the current of electricity passing through it."

Several methods have been proposed for exhibiting the revolution of an electrified wire about the poles of a magnet; but the author flatters himself, that that which he has contrived, affords a better example than any that has yet been shown, and certainly has a

more pleasing effect. It consists of helical coils instead of the straight wires formerly used: these wires are suspended on the poles of a horseshoe-formed magnet; and when the electric current is passed along them, they revolve on their axis in contrary directions. The direction of rotation is reversed when the direction of the current is reversed.

M. Ampere, learning the result of Mr. Faraday's experiments, and reasoning thereon, was led to infer that a magnet might be made to rotate on its axis, within the electric current which it conducted itself; and succeeded in producing the effect he anticipated. The same philosopher constructed an apparatus to show a rotating electrified wire, independently of a separate voltaic battery. In his apparatus the electricity is produced by the instrument itself: it consists of a double cylinder of copper, between the interior surfaces of which a cylinder of zinc is introduced, suspended by arched wires on a pivot attached to another arched wire, by which the whole machine is sustained on the pole of a strong bar magnet, inserted through the interior copper cylinder. When diluted acid is poured into the copper cylindrical cell, the zinc cylinder, being free to move upon its point of suspension, begins to revolve with a greater or less velocity, depending on the strength of the acid and the power of the magnet. If the apparatus be constructed sufficiently light, and delicately suspended, it will revolve by the agency of terrestrial magnetism.

A pleasing addition has been made to the apparatus of M. Ampere by Mr. Marsh. In his arrangement, a compound motion takes place, the zinc cylinder revolving in one direction, and the copper vessel in another. Mr. Barlow, of the Royal Military Academy at Woolwich, in his valuable *Essay on Magnetic Attractions*, has attempted to reduce the law of induced magnetism to mathematical principles, and upon similar principles to establish the law of electro-magnetism.

After going through all the experiments of M. Oersted, MM. Ampere and Arago, of Sir H. Davy and Mr. Faraday, he was led to consider that the seeming irregularity of the effect produced by the action of an electrified wire on a magnetic needle, might be accounted for in this way; "that every particle of the electric fluid in the conducting wire acts on every particle of the magnetic fluid in a magnetized needle, with a force varying inversely as the square

of the distance; but that the action of the particles of the fluid in the wire is neither to attract nor to repel either pole of a magnetic particle, but a tangential force, which has a tendency to place the poles of either fluid at right angles to those of the other; whereby a magnetic particle, supposing it under the influence of the wire only, would always place itself at right angles to the line let fall from it perpendicular to the wire, and to the direction of the wire itself at that point."

This gentleman in the course of his experiments discovered several new facts, and constructed some pleasing apparatus to illustrate them. One of these consisted of a light hollow metallic cylinder, having a steel point passing downwards into an agate cap fixed to the upper end of a magnet; the magnet was supported in a vertical position by a foot. The lower extremity of the cylinder dipped into mercury contained in a hollow groove of a large wooden cup, turned to fit the magnet. In this apparatus the voltaic battery and connecting wires were so arranged that the electric current was transmitted through the cylinder, and it immediately assumed a rotatory motion. If we conceive, as Mr. Barlow did, that the cylinder consists of an infinite number of bent wires, this apparatus will exhibit the electrified wire rotating on its axis.

The effect of a horseshoe magnet on an electrified wire freely suspended was first shown by Mr. Marsh. The lower end of a pendent wire was made lightly to touch the surface of mercury contained in a trough, and a horseshoe-formed magnet so placed that the wire hung between its poles; and when a current of electricity was passed through the wire it was thrown out, and the contact being broken, it fell again by its own gravity into the cup of mercury, was again projected, and again fell back into its place. When connecting wires were changed, or the position of the magnet reversed, the same thing happened, only the wire started out in an opposite direction. The cause of this peculiar motion is explained by Mr. Barlow in the following manner: "that the wire having a tendency to pass round the north end of a magnet to the right hand, and round the south end to the left hand, is urged by equal forces directly in a line with the open space of the magnet, the equality of the two forces preventing the rotatory motion about either, but both conspiring to give the rectilineal motion which has been described."

It immediately occurred to the sagacious mind of Mr. Barlow, as in the instance of the vibrating wire, that as it only formed one radius of a circle, the employment of a succession of radii would produce rotatory motion. On arranging an apparatus in the form of a star, so adjusted that one of its radii touched the mercury, the magnet and other parts being in the same condition as in the preceding experiment; on the connection being made with the battery, the star immediately acquired a rotatory motion; when the contact was altered or the magnet reversed, the motion of the star was also reversed; but if both were reversed, the revolution continued the same.

Unless the electrical power employed in this experiment be sufficient to throw out the one radius to such a distance as will bring another on to the surface of the mercury, the effect produced will be only equal to that of the single pendent wire. An improvement to obviate this was proposed by Mr. Sturgeon. It was to employ a circular metallic disc instead of the star, by which means one part of the periphery was always in contact with the mercury.

Professor Moll in repeating and extending the experiments of M. Seebeck, which will be adverted to presently, observed that an electric current was established in one metal by the action of acids on its extremities. A slip of zinc was bent into a rectangular frame open at one end, and the extremities of the metals coiled up so as to be in contact. The ends were inserted into a small vessel with the coil to the south, and the whole ranged in the magnetic meridian with the needle inside the zinc. On placing a small portion of dilute sulphuric acid in the vessel, the needle first deviated to the east, but soon afterwards turned to the west, and then gradually returned to the magnetic meridian. While the needle was deflected, a bar of copper was introduced into the fluid and made to touch the zinc; the needle was then considerably agitated, and turned round several times. A similar experiment was tried with copper: when nitric acid was added to the water, a deviation of the needle to the west was perceptible, but no effect was observable when sulphuric acid was employed, excepting when a bar of zinc was made to touch that part of the copper immersed in the fluid.

The electricity here excited is not voltaic, but is produced by the oxidation of the metal, or the disturbance of the equilibrium of temperature in the metal, by the heat evolved by the mixture of

the two fluids. When a rectangle is formed of two metals, and their coiled extremities in contact, and immersed in diluted sulphuric acid, the deflection of the needle is the reverse of that produced by the application of the heat of a spirit-lamp.

When lead and bismuth, lead and tin, iron and bismuth, cobalt and antimony, are immersed in concentrated nitric acid, they develope electro-magnetic phænomena, which is indicated by the galvanoscope or multiplier in communication with the metals. To obtain these effects, the surfaces of the metals should be clear of oxide; and it is remarked that little or no effect is produced by the metals being immersed in dilute nitric acid. When bismuth and lead are used, the concentrated nitric acid acts more powerfully on the bismuth than upon the lead; and dilute acid on the contrary, acts more strongly upon the lead than the bismuth. Hence it is concluded, that lead acts as the plus metal in the dilute acid, and the minus metal in the concentrated acid. When two bars of zinc are immersed in a diluted solution of sulphuric acid, that piece of metal which first enters the fluid is plus to the other, which may be exhibited by the assistance of the multiplier or galvanoscope.

These experiments tend greatly to support the theory of Dr. Wollaston, respecting the primary source of electricity being produced by the oxidation of the metals; for if contact was sufficient, the same metal would be plus, whether immersed in a diluted or concentrated acid solution, which it appears is not the fact.

We have shown that a metallic wire, while an electric stream passes along it, assumes the character of an artificial magnet. M. Ampere, from his views of magnetism, was led to suspect that if a metallic disc was put into rapid motion while placed near to an electrified wire, that that wire would rotate in a manner similar to a magnet subjected to the same procedure;—and such he found to be really the case.

If a double helical coil of copper wire be freely suspended in approximation with and above a circular metallic plate, ranged in an horizontal position, so that a rapid rotatory motion may be communicated to it; while the electric stream flows through the wire, and the metallic plate is in motion, the wire acquires a similar rotatory movement, which is continuous as long as the plate rotates, or the connection with the poles of the battery and the

helical coil is preserved. Upon reversing the rotation of the plate, that of the helical coil of wire is reversed also. A stretched sheet of paper may be interposed between the plate and wire, but the effects will be precisely the same.

We have now, we believe, completed the description of all the leading facts that have been developed in electro-magnetic science, by the aid of electricity excited in the voltaic combination: but there is another class of experiments, equal if not surpassing in importance those we have described, wherein the electricity is elicited by the disturbance of the equilibrium of temperature of different metals, and gives evidence of possessing characters analogous to that of the voltaic battery, by its action on the magnetic needle, upon the nerves of a frog, and power of producing rotatory motion.

The honour of this discovery is due to Professor Seebeck, member of the Academy of Berlin, who first observed that an electric current might be established in metals without the aid of a liquid or of oxidation. All metallic bodies elicit electro-magnetic action when the equilibrium of temperature is disturbed; and the effects produced on the magnetic needle, placed within the influence of the metallic body thus treated, is acted upon with an energy proportional to the difference of temperature in that metallic body. As the essential, if not the sole condition, necessary to excite a thermo-electric current is, that the extremities should be in opposite states as regards temperature, the minutest metallic specimens are found to exhibit thermo-electric action, when their surfaces are unequally heated.

The apparatus for exhibiting the thermo-electric action on the magnetic needle is very simple. It originally consisted of two different metals, soldered together at their extremities, formed into frames either of a circular, or a quadrilateral, or a rectangular figure, and electricity was excited by the application of heat to either of those places where the two metals were in contact.

The same effects are produced when the extremities of the two metals are riveted, or bound together by a few turns of wire, as when they are soldered; perfect contact being all that is necessary.

If a rod of antimony be connected at its extremities by twisting a piece of brass wire round each of them, so as to form a loop,

each end of the bar having several coils of the wire; if one of the extremities be heated for a short time with a spirit-lamp,—electro-magnetic phænomena will be exhibited on its being brought near to a freely suspended needle; and it will be found that the brass wire is in that state which would be produced by connecting its heated end with the minus pole of a voltaic combination, and its cold end with the plus pole.

That species of electricity which is elicited by the disturbance of the equilibrium of temperature in a metallic body, is denominated thermo-electricity, in contradistinction to the term hydro-electricity, applied to that which emanates from a voltaic combination.

The electricity developed by a metal when its extremities are unequally heated is necessarily very small: when therefore we desire to detect very feeble magnetic action, and do not use the multiplier, it is necessary that we employ very sensible magnetic apparatus. Among the best may be mentioned the astatic needle, which may consist of two light steel needles ranged parallel one above the other, having the same axis; the magnetic virtue should be imparted as uniformly as possible to each, and their opposite poles be in approximation. When a compound needle of this description is freely suspended, it has little or no tendency to arrange itself in the magnetic meridian; the perfection of the neutralization of the earth's magnetism is principally dependent on the uniform structure of the steel composing the two needles, and upon the equality of magnetic power developed by the needles.

Another delicate magnetic apparatus for experiments is afforded by suspending a piece of wheat straw, with a few twists of floss silk by its centre. At its extremities must be placed two small sewing-needles to which magnetism has been communicated, ranged so that the terrestrial magnetism exerts little or no influence on the combination, which, when in equilibrium, will be found extremely susceptible of feeble electro-magnetic action. The delicacy of the arrangement will be improved by attention to the length of the straw lever, and to the position of the small magnetized needles, which should be so placed, that all directive force for the earth's magnetic poles be destroyed; when that is the case, the straw lever will remain at rest in any position. It necessarily fol-

lows that these compound needles offer considerable advantages for the detection of feeble electro-magnetic action, as the directive force in them is destroyed, or nearly so; and consequently any action, however slight, that may be exerted by a feebly electrified body on them, is rendered visible and readily recorded.

When rectangular frames, composed of one, two, or more metals, are experimented with, the maximum effects are produced when the extremities of the elements are in the extreme states as regards temperature; and it is therefore advisable to abstract heat from one extremity at the same time that it is added to the other. The deviation of the needle is in an opposite direction when placed outside the frame to that when placed inside the frame. When the extremities of the metals are in perfect contact, and the source of heat applied for a longer time, the thermo-electric action is more powerful when the frame is placed at right angles to the magnetic meridian, and the needle is at rest in its natural position.

A thermo-electric apparatus may be formed with three bars of antimony and three bars of bismuth, soldered together alternately; this hexagonal figure being supported horizontally, and a magnetic needle delicately suspended within it, with one side of the hexagon in close approximation, above, and parallel to the needle; upon elevating or depressing the temperature of either one of the joined parts, a deflection of the needle is perceptible, which may be increased by applying the heating or cooling process to other united parts that are not contiguous; an augmentation of effect is obtained by reducing the temperature of one soldered part, while the other is elevated.

Experiments determine that several other metals besides bismuth and antimony, properly arranged, and under the same conditions, exhibit thermo-electric phænomena when their extremities are unequally heated. The thermo-electric action exhibited by a combined apparatus is enlarged by the employment of a more numerous set of bars, and modified by the adaptation of different metals.

It has been proved that a thermo-electric current can be established and made evident in one metal only, by the disturbance of the equilibrium of temperature in that metal; and the tendency which it has to deflect the magnetic needle in any particular direc-

tion, seems dependent upon the form given to it in casting. A singular difference is produced when the metal is cooled slowly or rapidly, occasioned, it is conceived, by a relation existing between the crystalline structure and magnetic property of the metal.

Various instruments have been constructed and recommended for multiplying the effects of feeble electro-magnetic action. Among the most approved may be classed those of M. Poggendorf, M. Schweigger, M. Oersted, and Professor Cumming; but that contrived by the latter philosopher is the most simple. It is called a multiplier or galvanoscope, and consists of a copper conducting wire $\frac{1}{30}$th of an inch diameter, covered with twisted silk to prevent contact; this is bent into eight or ten circumvolutions of a rectangular form; a magnetic needle is suspended horizontally within the conductor, and the whole is fixed on a board, a divided circle being placed under the wires. To correct the directive force of the needle towards the earth's magnetic pole, Professor Cumming employed an astatic needle. The current is completed from one cup to the other, through the wire of the rectangle.

The effect of the galvanoscope or multiplier is founded upon the equal action which every part of a conducting wire, when it transmits a current, exerts upon the magnetic needle; and it will easily be conceived that the needle receives an impulse exactly in proportion to the number of circumvolutions. The impulse given by each branch has also the same direction, since it is in fact the same side of the wire which in both branches is opposite the needle. When the multiplier or galvanoscope is employed for strong electro-magnetic action, the wire forming the circumvolutions must be increased in proportion; otherwise the effect may be diminished instead of increased, in consequence of the imperfectness of the conductor. The thermo-electric properties of the metals have no connection either with their galvanic relations, or their capacity for conducting heat or electricity; neither do they accord with their specific gravities, nor their atomic weights.

In forming a thermo-electric series, it is desirable to combine an extreme positive with an extreme negative metal; we therefore subjoin a table collected and laid down by Professor Cumming. Every substance in the series is plus to that which precedes it, and minus to that which follows it.

Thermo-electric Series.	*Voltaic Series, by Acids.*	*Series of Conductors.*	
		Of Electricity.	*Of Heat.*
Galena.	Potassium.	Silver.	Silver.
Bismuth.	Barium.	Copper.	Gold.
Mercury.	Zinc.	Lead.	Tin.
Nickel.	Cadmium.	Gold.	Copper.
Platinum.	Tin.	Brass.	Platinum.
Palladium.	Iron.	Zinc.	Iron.
Cobalt.	Bismuth.	Tin.	Lead.
Manganese.	Antimony.	Platinum.	
Tin.	Lead.	Palladium.	
Lead.	Copper.	Iron.	
Brass.	Silver.		
Rhodium.	Palladium.		
Gold.	Tellurium.		
Copper.	Gold.		
Silver.	Charcoal.		
Zinc.	Platinum.		
Cadmium.	Iridium.		
Charcoal.	Rhodium.		
Plumbago.			
Iron.			
Arsenic.			
Antimony.			

M. Becquerel, in his researches for the law of electrical effects when two metals were united, and their temperatures equally varied, deduced from his experiments, " that in a circuit formed of two metallic wires, soldered end to end, when we raise each of the joints to different temperatures, the resulting electro-dynamic intensity is equal to the difference of the forces produced successively by each of the temperatures, in the same joint, the other being at zero, and not to the intensity of the force produced by the difference of temperature alone. The intensity of the electric current diminishes proportionally to the diminution of temperature."

The rotation produced by the reciprocal action of a thermo-electric current and magnet, is exhibited by a rectangular frame composed of silver and platinum, or copper and platinum wires, soldered together: in the lower part of the frame a ring should be formed to receive the support or stand, upon the top of which the frame is freely suspended by means of a fine steel point affixed to its upper part. If a bar magnet be placed on one side of the rectangular frame, and the flame of a spirit-lamp brought into contact

with the lower end of the other side, a thermo-electric current is established, and the instrument moves round until that side originally opposed to the magnet enters the flame; it then moves back again, and at length remains at right angles to the lamp and magnet. When two magnets are used and posited at each branch, and the heat applied at either end, the frame completes a revolution: when all the circumstances are the same as in the first instance, another impulse is given, and the rotation amounts to twenty or thirty revolutions in a minute. The arrangement is improved by forming the wires into compound rectangular frames; these being supported on the extremities of a horseshoe magnet, and the lamp placed equidistant between them, the apparatus is put in action, and the compound frames revolve in contrary directions.

The revolution of four compound rectangular frames is produced by mounting them upon stands one on each side of the poles of a powerful bar magnet, and bringing the flame of a spirit-lamp into contact with the lower angles of the frames; when it will be found (provided the magnet be placed in the magnetic meridian) that the north-eastern frame will vibrate a few times when the flame is held towards its exterior, and then remain at rest, with its arms equidistant from the flame, and will revolve when the flame is placed towards it interiorly. On the contrary, when the flame is held on the exterior of the north-western frame, it will revolve; and on being removed to its interior, it first vibrates, and then remains at rest. If the lamp be removed to the exterior of the south-eastern frame, it will vibrate, and finally remain at rest; but on bringing it to the interior of it, it will revolve. Again, on placing the flame on the exterior of the south-western frame, it will revolve; but on bringing it to the interior, it will only vibrate, and finally remain stationary. These effects will be reversed on changing the position of the magnet: it is not however absolutely necessary that the magnet should be placed in the magnetic meridian; but it was convenient to place it so, for the purposes of illustrating the above phænomena. The revolutions of the compound rectangular frames follow the impulse first given to them; although they seem to revolve more freely in one direction than another, namely, towards the poles of the magnet.

When two powerful bar magnets are placed parallel to each other in the magnetic meridian, with their poles in opposite direc-

tions, and the north-pole of the western magnet pointing towards the north; upon placing a compound rectangular frame, similar to those described, and mounted upon a proper stand, so as to turn freely round, between the extremities of the magnets which point in the northern direction, and bringing the flame of a spirit-lamp into contact with the exterior of the frame,—it will vibrate a few times, and then remain at rest as in the foregoing experiment; but upon placing the flame in contact with its interior, and between the magnets, it will assume a rotatory movement. On bringing the frame within the opposite poles of the magnets, and placing the lamp on its exterior, it will vibrate for a short time and at length remain stationary; but on placing the flame between the two magnets, and bringing it into contact with the interior of the frame, it will revolve. On changing the situations of the two magnets, or reversing their poles, the frames will revolve when the flame is placed exteriorly in regard to them, and will vibrate till they remain at rest on placing the flame interiorly, being the reverse of the last experiment*.

The thermo-electric current deflects the magnetic needle, acts upon the nerves of a frog, and produces rotatory motion; but no person has hitherto succeeded in fusing wire, or of producing decomposition by its agency: in consequence, it is presumed, of the thermo-electric current possessing little or no power of tension.

Experiments teach us, that the same thermo-electric elements which act powerfully on the magnetic needle when the communication is by a short and thick conductor, act feebly when it is long and fine; the effects therefore cannot be transmitted or multiplied beyond a certain extent, even by the best conductors.

The electric current passes along a conductor with a greater facility, as it is the more *intense;* and as the hydro-electric current pervades the wire of the galvanoscope or multiplier more readily than the thermo-electric current,—it follows as a necessary consequence, that the hydro-electric current develops electricity of greater *intensity* than that of the thermo-electric current.

The amount of the angle of deviation of the magnetic needle

---

* These two experiments, if not decidedly new, have never before been communicated to the public.

caused by the action of an electric current is proportionate to the *quantity* and not to the *intensity* possessed by the current. We learn therefore from the effects produced by thermo-electric elements on the magnetic needle, that the thermo-electric current is of that species termed *quantity*, which it possesses in a much greater degree than the hydro-electric current of similar size; but the *intensity* of force in the former is very inferior to that in the latter; and it would perhaps be necessary to employ an electric circuit of many hundred elements, to pass the current through a liquid conductor with the same freedom as is effected by the hydro-electric current from a voltaic pile composed of four or five elements.

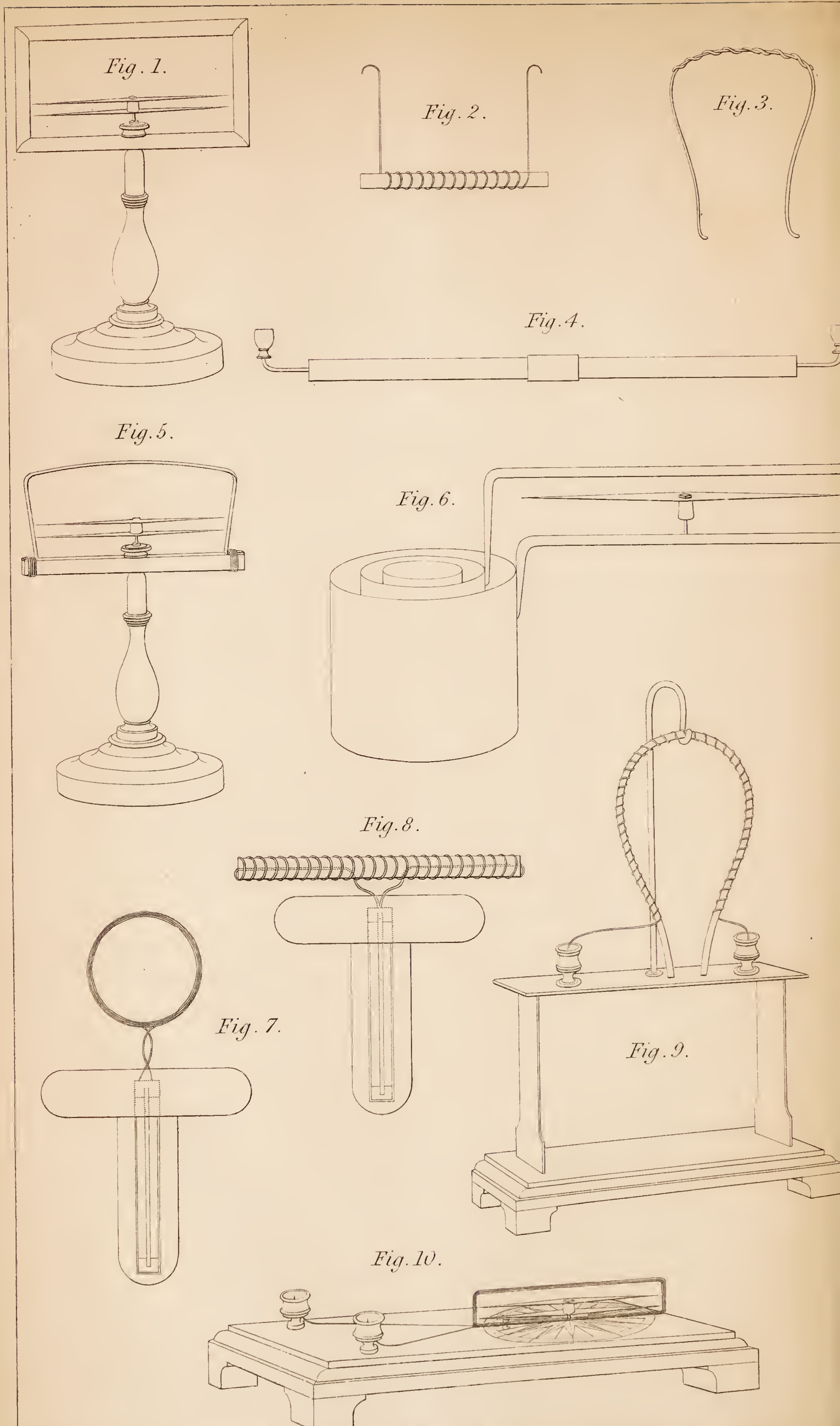
Attempts have been made to employ at the same time hydro-electric and thermo-electric elements, the former giving *intensity*, and the latter *quantity*; but without success. It was found that when the hydro-electric and thermo-electric elements formed the circuit, the latter actually diminished the effect; for it added to the length of the circuit, and by heating, diminished the conducting power; and this loss was not at all compensated by any addition supposed to be derived from thermo-electric action.

Experiment and observation show that tension is perfect in the ordinary electricity excited by friction on glass; for it may be accumulated until it forces a passage through any non-conductor. Tension is imperfect in voltaic electricity, from its passage being retarded by the fluid conductor employed in the combination; and there is little or no tension in a thermo-electric system, since the current flows equally through every part of it.

In concluding this brief sketch of electro-magnetism, or electro-dynamics, we beg leave to state, that nothing more has been attempted than to explain in a clear and concise manner the several facts of a science now in its infancy. From the extraordinary results which have been already developed, and from the promise it seems to hold out, of being the means of unfolding a more intimate knowledge of electricity and magnetism; it is entitled to rank with, if not to surpass, the most brilliant discoveries of the present day.

No particular theory has been maintained; those noticed for the sake of precision are in the words of their several authors: and it is therefore left to the discretion of the reader to adopt that

which he may most approve. There are several hypotheses which have not been noticed; they are ingenious and plausible, particularly that of Professor Hanstein, and with which we shall close our remarks. "In the completed voltaic circuit, the conductor is traversed in an opposite direction by the opposite electricities. Every plus elementary particle strives to combine with a minus one; thus united in pairs, they neutralize each other, and their electric power disappears. But in the neutral state they perhaps appear as elastic fluid *elementary magnets*, which so surround the surface of the polar wire that all north poles are turned on one side, and all south poles on another; and the axis of every elementary magnet is the tangent of the circular section of the conducting wire. Owing to the constantly aggregating quantity of electricity from both ends of the wire, and the expansive nature of electricity, these elementary magnets are forced out of the surface of the wire with a velocity equal perhaps to that of light itself. As long, therefore, as the circuit is uninterrupted, the wire is surrounded by a cylindrical atmosphere of neutralized molecules combined in pairs, each pair of which has a magnetic north pole and south pole, and a neutral point."



Published, July 1st 1828, by Watkins & Hill, Charing Cross. London.

E. Turr

DESCRIPTION OF APPARATUS CONSTRUCTED AND SOLD BY WATKINS AND HILL,

FOR ILLUSTRATING THE MOST STRIKING PHÆNOMENA OF ELECTRO-MAGNETISM.

Fig. 1. plate I. represents a compound rectangular frame; one half of it is formed of bismuth, and the other half of antimony, united at opposite corners. This frame is erected in a vertical position upon the upper end of a pedestal; it has a hole made in it through which passes a screwed wire, having a binding nut upon it, by which the frame is firmly secured to the pedestal. The upper end of this wire terminates in a fine point, upon which turns a magnetic needle. If the frame be placed in the magnetic meridian, and the needle at rest in its natural position within it, upon applying a spirit-lamp to the lower end of the frame, where the two metals adjoin to each other, a thermo-electric current is established, and rendered manifest by the deflection of the magnetic needle. Similar phænomena are also exhibited by abstracting heat from one part of the frame instead of communicating heat to it; thus proving that thermo-electricity is excited by the disturbance of the equilibrium of temperature in the frame. If, for instance, one of the compounded corners be enveloped in an absorbent substance, such as filtering paper, and this paper be moistened with any rapidly evaporating fluid, which may be ether, &c. the cold thereby produced, or the diminished temperature of that corner of the frame, is sufficient to excite thermo-electricity, which will cause the needle to be deflected in an opposite direction to that in which it is deflected when heat is applied. The maximum effects are produced when the extremities of the elements are in extreme states as regards temperature; it is therefore advisable to abstract heat from one corner of the rectangle, at the same time that it is added to the opposite corner. In this, and in all other apparatus where so feeble a current as that produced by a mere difference of temperature in the extremities of any body composed of a metal or metals is to be made manifest, it becomes necessary to

neutralize the effects of terrestrial magnetism upon the needle: to obtain this end, we may either employ the astatic needle, formerly described and recommended, or arrange an artificial magnet or magnets in such a manner, as to overcome the directive tendency of the needle, which may be known by the needle remaining stationary in any position in which it may be placed.

Fig. 2. plate I. represents a glass tube with a copper wire coiled round it; the ends of the wires are bent at right angles in the same direction, for the convenience of being inserted into the cups containing mercury, affixed to the cylindrical battery (fig. 21.), or into those cups on the stand (fig. 9.), for which purpose the horse-shoe-formed wire must be removed. The points of the wires should be clean or amalgamated; and when the apparatus is supported by these wires, it affords a ready mode for inducing magnetism on steel needles by the electric current. For this purpose, the battery should be excited, and the needles either introduced partially, or their whole length, but they must be withdrawn immediately, as the maximum effects are produced instantaneously; and if allowed to remain, the magnetism will be reversed, if not entirely destroyed. The direction of the polarity of the magnetism acquired by the needle, submitted to the influence of electricity passed through a helix, is dependent on the manner in which the wire is coiled, whether it proceeds from the right downwards to the left, or from the left downwards to the right.

Fig. 3. plate I. represents an apparatus for showing the thermo-electric action of compound wires. It consists either of a platinum and a silver wire, or of a platinum and a copper wire, twisted together at one end, their other ends being formed into a convenient shape for inserting them into two cups containing mercury, attached to a galvanoscope. Upon bringing the flame of a spirit-lamp into contact with the twisted part of the wires, the electricity, excited by the disturbed equilibrium of temperature in the wires, will be manifested by the deflection of the magnetic needle attached to the galvanoscope.

Fig. 4. plate I. exhibits an apparatus to show the thermo-electric action manifested by a compound bar, when the equilibrium of its temperature is disturbed. The bar is formed of a rod of bismuth, and another of antimony, united into the bar shown in the figure, by being fused or melted together: to each end of this com-

pound bar, a bent copper wire is affixed, each of which supports a cup to contain mercury. Upon making a communication with a galvanoscope in the usual manner, by means of two connecting wires inserted into the mercury held in the cups, and bringing the flame of a spirit-lamp into contact with the centre of the bar, thermo-electric effects will be shown in the galvanoscope, by the deflection of the magnetic needle.

Fig. 5. plate I. represents a compound rectangular frame, composed of copper and antimony, or copper and bismuth. A bar, either of antimony or bismuth, is affixed to the top of a metal cap, mounted upon a wooden pedestal, by means of a screwed brass wire, passed through a hole made in the bar, and secured by a screwed nut; the upper end of the wire terminating in a fine conical point, on which a magnetic needle turns freely. To the bar, a staple, formed of bent sheet copper, is bound by means of copper wire, wrapped round the ends of it. Upon applying the heat of a spirit-lamp to either end of the bar, or abstracting the caloric from it by the evaporation of a volatile fluid, so as in either case to disturb the equilibrium of temperature in the bar, thermo-electric effects are produced, and exhibited by the deflection of the needle.

Fig. 6. plate I. represents a small cylindrical battery, with a connecting wire attached to it.

This simple and convenient arrangement consists of a double cylindrical copper vessel, having an insulated hollow cylinder of zinc placed within it. A copper wire is soldered to each, and bent into a rectangular shape, having also a conical pointed wire affixed to it, on which a magnetic needle can be placed, so as to turn with great freedom. Upon pouring dilute acid into the copper vessel, voltaic effects will be instantly manifested by the deflection of the needle, from the magnetic meridian, in which plane the rectangular wire ought to be previously placed.

The advantage of this combination is, that we can avoid the necessity of having cups to hold mercury, and the consequent occasion continually to amalgamate the ends of the connecting wires.

Fig. 7. plate I. exhibits an apparatus to show the directive force of an electrified wire. It consists of a glass cylindrical vessel, having a cork float attached to its upper end. Into this vessel

is inserted a small voltaic combination, formed upon the plan recommended by Dr. Wollaston, and consisting of a plate of zinc, surrounded by a copper plate, the zinc plate being insulated upon its edges. A copper wire, affixed by soldering to both these plates, is made into the form of a ring, consisting of several coils of the wire, which is besides insulated, by being wrapped round with silk thread: upon pouring dilute acid into the glass vessel, and placing the plates in it, voltaic action commences, and is manifested by placing the apparatus afloat in water; when the coil will have a tendency to take a position in the plane of the magnetic meridian. The magnetic effect is still more strongly developed on bringing into the vicinity of the coil a powerful bar magnet; the wire being a temporary magnet, having each side of the coil in different states, as regards polarity. Also if the bar magnet be held horizontally in a line coinciding with the axis of the coil, it will be attracted, and continue to advance slowly until the coil or ring envelopes the pole of the magnet; when it proceeds with considerable velocity to the equator, or centre of the magnet, where it remains at rest. If now the magnet be withdrawn from the ring, and its opposite pole be placed within it, the ring recedes until it gets off the magnet; when it turns itself half round, presenting its opposite side to the magnet, and instantly approaching it, rushes forwards until it has again arrived at its centre, where it remains stationary as before.

Fig. 8. plate I. represents another arrangement for showing the directive property of an electrified wire.

The floating glass vessel and voltaic combination are similar to those described in the preceding apparatus: but the copper insulated wire; instead of being coiled into the form of a ring, is made of a helical shape, the two ends of the wire being returned through the middle of the helix and brought out near its centre, and soldered to the zinc and copper plates. Upon exciting electricity by pouring dilute acid into the glass vessel as before, placing the metallic plates within it, and setting it afloat, the helix assumes a polar arrangement; its opposite ends indicating different states of magnetism, so as to be attracted or repelled by either pole of a magnet held towards it.

Fig. 9. plate I. exhibits an apparatus to show that a metallic wire, while the electric current is transmitted along it, possesses

magnetic properties. It consists of a piece of soft iron wire bent into a horseshoe-form, suspended from a brass support, and having a copper wire coiled round it, the ends of which dip into two metallic cups containing mercury. If two connecting wires, proceeding from the voltaic battery, be then inserted into the mercury contained in the metallic cups, the electric current flows along the copper coil, and the iron wire inclosed within it, which thus rendered magnetical, will support a bar of iron upon its ends during the voltaic action, as though it were a real magnet; but instantly the communication is interrupted, with either of the extremities of the battery, by removing one of the connecting wires from the metallic cup, the piece of attracted iron falls from the ends of the bent horseshoe-formed wire; thus proving that the magnetic action developed in that wire was owing to the presence of voltaic electricity. The bent wire is elevated upon a wooden stand, as shown in the figure.

The same effect may be shown by using a straight, instead of a curved iron wire, when surrounded by a similar coil of copper wire, and connected in the same way with the battery; a piece of iron being capable of being supported at each end, or pole of the straight wire.

Fig. 10. plate I. represents the galvanoscope or multiplier. This apparatus exhibits in a striking manner very feeble electric currents. It consists of a copper wire, surrounded with a silken thread coiled or wrapped round it, for the purpose of insulating the different circumvolutions, into which the copper wire is bent, from each other. This copper wire so insulated, is bent into a rectangular frame, within which passes the steel or metallic point; upon this is suspended a magnetic needle, the point being surrounded by a graduated circle, in manner of the compass. The greater the number of coils of wire forming the rectangular frame, the greater is the magnetic energy displayed by the deflection of the needle; provided that on increasing the size of the battery, the thickness of the wire is also increased. But it must be remembered, that a thermo-electric action cannot be multiplied beyond a certain extent. Each end of the wire is made to enter into a metallic cup containing mercury; into these cups connecting wires from any apparatus must be placed, of which we wish to detect or measure the electric action; and the whole is mounted

upon a wooden basis or support. An astatic needle is represented as being suspended within the rectangular frame; but a common needle will do for general purposes, especially if the terrestrial influence is neutralized by magnets in the manner bef[illegible] described.

Fig. 11. plate II. represents an apparatus to exhibit the rotation of two metallic cylinders. A horseshoe magnet is supported vertically upon a stand, having holes formed in the centres of its ends. Two wooden circular troughs are secured by binding-screws, upon the arms of the magnet, to contain mercury. Into the holes in the centres of the ends of the magnet, two conical pointed wires are inserted, which are affixed in the middle of two hemispherical caps, united to cylinders, the rims of which are formed into points, which are dipped into the mercury contained in the circular troughs. Upon the top of each hemisphere is posited a small platinum cup to contain mercury. Other cups for holding mercury are supported upon the external ends of bent wires, which pass through the sides of the circular troughs, into the mercury contained therein. When a stream of voltaic electricity is passed through this apparatus by means of connecting wires, placed in the mercury contained in the upper and lower cups, the rotation of the cylinders commences, they turning in opposite directions; the rapidity of their motion and its continuance depending upon the energy of the voltaic battery employed.

Fig. 12. Plate II. represents an apparatus to exhibit the revolution of an electrified wire. It consists of a glass cylinder, mounted upon an iron wire, affixed to a wooden support, and having a copper wire loop passed through the centre of its top, and a metal cup to contain mercury above the wire loop. The soft iron wire of the support projects above the bottom of the glass cylinder, and is rounded at its top. Mercury is placed within the lower part of the glass cylinder, and also in another cup, formed in the wooden support. A platinum wire, having a loop formed at its upper end, is loosely hung to the loop above, and touches the surface of the mercury within the glass cylinder. Upon making a communication with a voltaic battery, by means of two connecting wires placed in the mercury in the upper and lower cups, and bringing a magnet into contact with the lower part of the iron wire, which projects below the wooden support for that purpose, the effects of

Fig. 11.

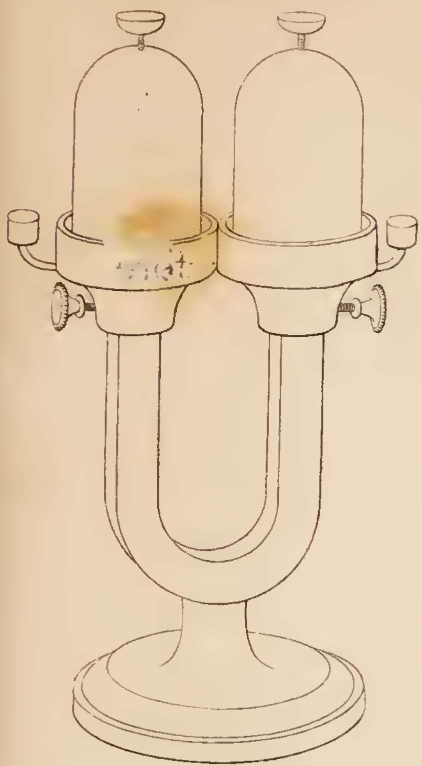


Fig. 12.

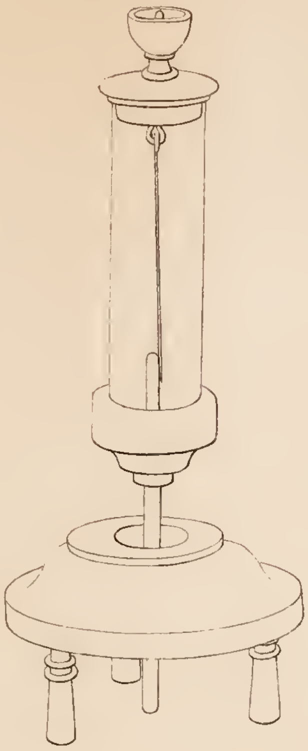


Fig. 13.

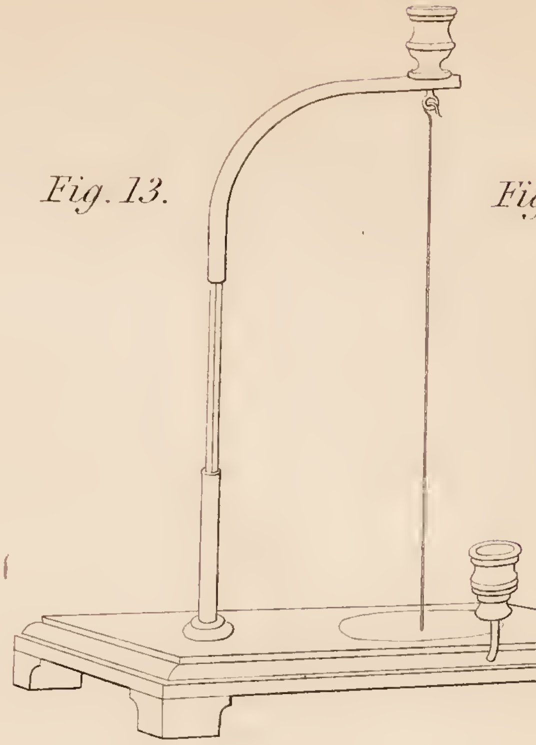
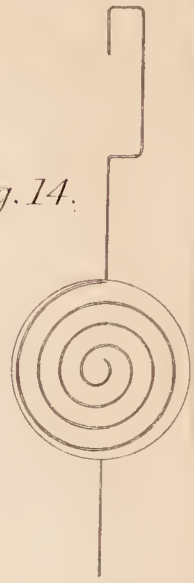


Fig. 14.



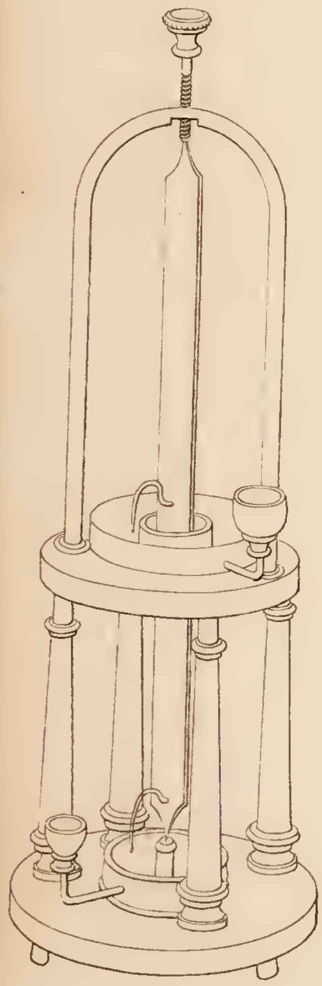


Fig. 15.

Fig. 16.

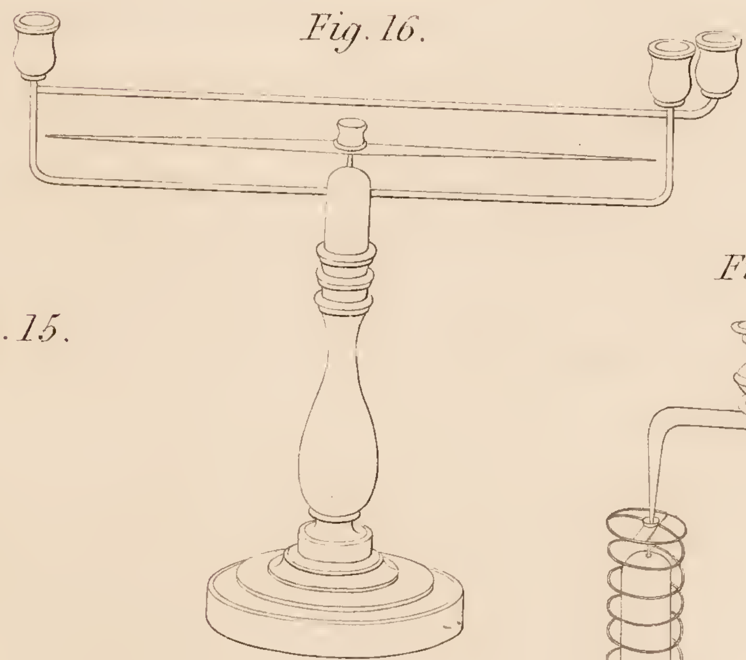


Fig. 18.

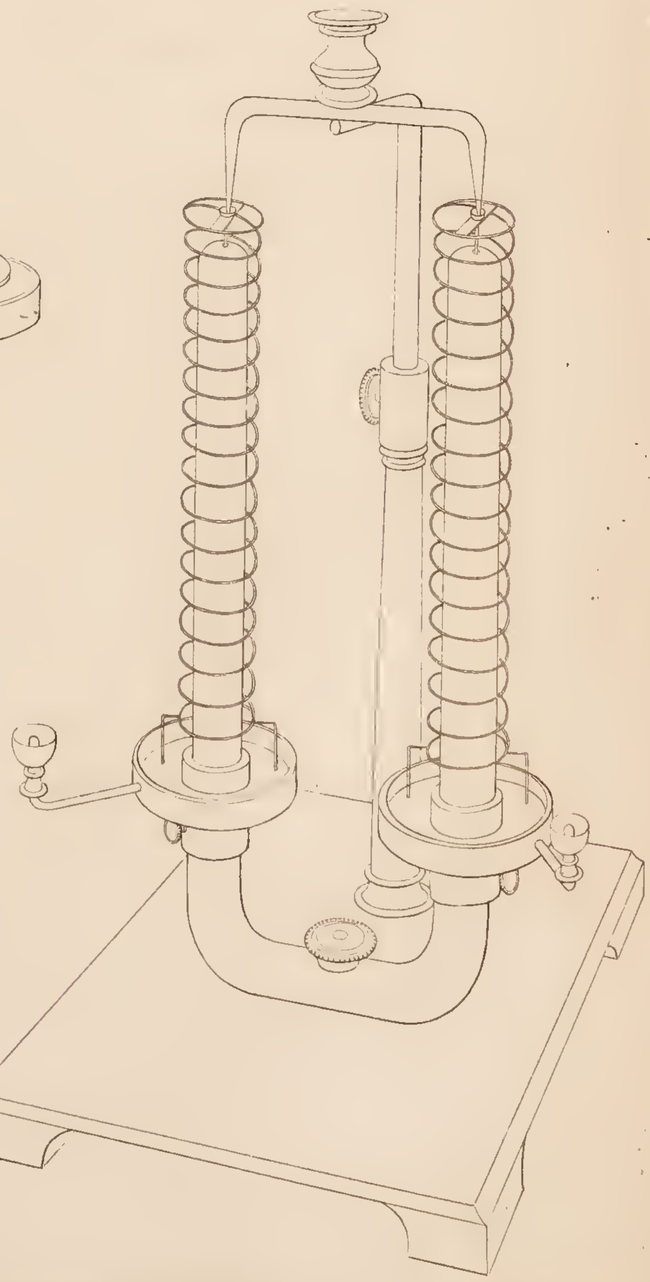
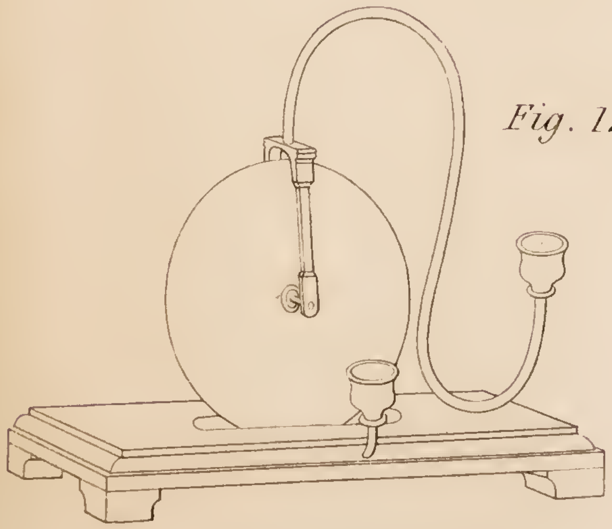


Fig. 17.



Published July 1st 1828, by Watkins & Hill, Charing Cross, London.

E. Turrell, sc.

the electro-magnetic action will be observed by the revolutions of the platinum wire round the iron wire, which is a magnet, whilst the real magnet is kept in contact with it. The wire generates the surface of a cone, its lower extremity the circumference of its base; hence the point of suspension is the vertex, and the iron wire magnet is in the centre of the base.

Fig. 13. plate II. represents an apparatus to show the vibratory motion communicated to an electrified wire, from the effects of a magnet. It consists of a wooden basis, upon which is affixed a bent brass standard, having at its upper end a vertical wire screwed into it, which wire supports a cup to contain mercury, and has at its lower end soldered a piece of platinum wire formed into a loop. To this loop is freely hung a light platinum wire, the lower end of which touches the surface of some mercury, which is contained in a trough formed in the wooden basis. Another cup to contain mercury is also affixed to another wire, which passes through the basis into the mercury in the trough. On making communication with a voltaic battery by means of two connecting wires, as usual, the current is made to pass along the loose platinum wire, and the circuit is thus completed; but no motion of the platinum wire is perceptible, until a powerful horseshoe magnet is placed in a horizontal position on the basis, with its poles inclosing the pendent wire, when that wire instantly acquires a vibratory motion. On reversing the situations of the connecting wires, or of the poles of the magnet, the vibrations will be in an opposite direction.

Fig. 14. plate II. exhibits an apparatus which, when adapted to the stand of fig. 13, illustrates the directive property of the freely suspended electrified wire. It consists of a slender copper wire, bent into a flat spiral coil, its upper end terminating in a reversed hook finely pointed, and its lower end pendent in a line coinciding with the pointed part of the reversed hook. The wire coil is secured to a circular disc of card, the wire from the central coil passing through the card and descending below it. When the straight wire is removed from the apparatus (fig. 13.), and the flat spiral coil arranged with the point of the reversed hook inserted in the top cup, and its lower extremity dipping into the mercury contained in the trough, the two ends being previously amalgamated, and the coil having free motion about its vertical

axis; upon transmitting electricity from a voltaic battery through the spiral coil of wire, it has a tendency to range itself in a plane perpendicular to the magnetic meridian, and is also very obedient to the magnet.

Fig. 15. plate II. represents an apparatus which exhibits the magnet rotating on its axis. A flat bar magnet is supported in a vertical position by an upright metal wire, affixed in the basis of the apparatus, and having a hole in its centre containing an agate cup, to receive the lower pointed end of the magnet; its upper end turns in another hole made in a vertical screw, with a milled head to turn it by, which is passed through a screwed hole made in an arched piece of wire, affixed to the upper part of the basis. Around the first-mentioned vertical wire, a cistern to contain mercury is provided; and another, having a hole in its centre to allow the magnet to pass through and revolve within it, near the middle of the magnet. These cisterns have metal wires projecting into them through their sides, to support cups which contain mercury, to effect the communication with the voltaic battery by means of uniting wires. Into the magnet two small bent and pointed wires are affixed, the ends of which dip into the mercury contained in the cisterns. When the voltaic circuit is complete, the magnet begins to rotate within the electricity, which it conducts itself, as it in fact forms part of the circuit; the rapidity of the revolutions of the magnet depending upon the delicacy of the sustaining point, the strength of the magnet, and the power of the battery employed. If we desire to actuate a large magnet, it is necessary an addition to the apparatus should be made by providing a cup affixed to the vertical screw to contain mercury, by which contrivance, and by employing an additional battery, a current of electricity can be passed from the top of the magnet to its equator; and as in the first-mentioned case, an opposite current can be passed from its lower end to the equator, and an additional electric force be obtained. The ends of all the wires should be amalgamated; and when the two currents are passed through the magnet, the conical hole of the vertical-screw should be amalgamated also, to insure contact with the point of the magnet inserted in it.

Fig. 16. plate II. exhibits an apparatus to show the effects produced when a straight connecting wire is placed parallel above or below a magnetic needle horizontally suspended. A copper

wire bent upwards at a right angle at each end, and passed through and secured in a hole, made across the upper end of a brass cap supported upon a wooden pedestal, is inserted into two metal cups to contain mercury. Another copper wire secured at one end to the former one, by being tied to it with a silken thread, saturated with shell lac varnish to insulate the wires; and having also another metal cup to contain mercury at the tied end of it, has its other end passed into the opposite cup. Upon the brass cap is posited a conical metal point, to support a magnetic needle turning upon that point as a centre. If the needle be allowed to assume its natural position, and the copper wires be placed in the direction of the magnetic meridian, upon making a communication with a voltaic battery, by means of connecting wires, with the two metal cups posited upon the turned-up ends of the first-mentioned copper wire, the electric energy will be conveyed *below* the needle and deflect it; the amount of the angle of deflection being in proportion to the power of the battery applied. If, however, one of the connecting wires be removed from the cup affixed upon one of the turned-up ends of the first-mentioned wire, and be placed in the adjoining cup affixed to the end of the other wire, the electric current will be transmitted along that wire, which is placed *above* the needle; and the needle will again be deflected, but in a contrary direction. The ends of the copper wires in the cups should be quite clean, or amalgamated.

Fig. 17. plate II. This apparatus exhibits the rotation of a circular metallic disc upon its centre, when an electric current traverses it and the disc between the poles of a horseshoe magnet. It consists of a circular plate or disc of copper nicely suspended upon its axis, which is formed of platinum, and turns in centres of the same metal; both to preserve contact, and to obviate the necessity of amalgamating them. The staple to which this disc is hung, is supported above by a bent wire affixed to the basis of the apparatus; at the opposite end of which is a cup to contain mercury, to keep the connection good, which is made by means of a wire united with one end of a voltaic battery. In the basis an oblong cavity is formed to contain mercury, into which the rim of the periphery of the disc dips; another metal cup affixed to a wire, which penetrates into the mercury contained in the oblong cavity, is also provided to hold mercury, and to re-

ceive the communicating wire from the other end of the voltaic battery, and thus a current through the apparatus is established. If a horseshoe magnet be placed with its poles extending underneath the axis of the disc, and resting upon the basis of the apparatus, the metallic disc will immediately assume a rotative action, the direction of which may be changed either by reversing the poles of the magnet, or the disposition of the connecting wires. It is necessary that the rim or periphery of the disc should but just touch the mercury in the oblong cavity, and also that it be amalgamated all round; to do which, it is best to remove it from its centres, and cleanse the edge thoroughly by a file or otherwise, and then by dipping a piece of wire into the nitrate of mercury as before described, and taking up upon it a portion of the mercury contained in the nitrate, it may be transferred to the edge of the disc, by rubbing the wire coated with mercury round it. It is necessary to observe, that in this, as in all other electro-magnetic experiments, if the electricity be feeble, we must employ powerful magnets to exhibit striking effects.

Fig. 18. plate II. is a view of an apparatus to show the contrary rotation of two electrified wires each about its respective axis by the joint effects of electricity and magnetism. It consists of a horseshoe magnet, firmly screwed to a wooden basis or support, two helical coils of copper wire, having slender bars across their tops with needle points in their centres, turning in conical holes drilled in the ends of the magnet, and above the points two small platinum cups to hold a globule of mercury in each. Two wooden cisterns are attached by screws on the lower parts of the magnet, having bent arms fixed in them. To the lower ends of the helical coils are soldered slender pointed wires, bent so as to enter slightly into mercury placed in the two larger cups, mercury being also placed in the small cups. A brass standard affixed to the basis of the apparatus has a forked piece attached to it, with two points descending into the two platinum cups upon the tops of the coils; and there is also another cup placed upon the forked piece to contain mercury. The voltaic circuit is completed by placing wires in the mercury contained in the small side cups, and connected with the copper parts of the batteries; and other wires communicating with the zinc parts are placed in the cup on the top of the apparatus. When the electric stream flows through

Fig. 19.

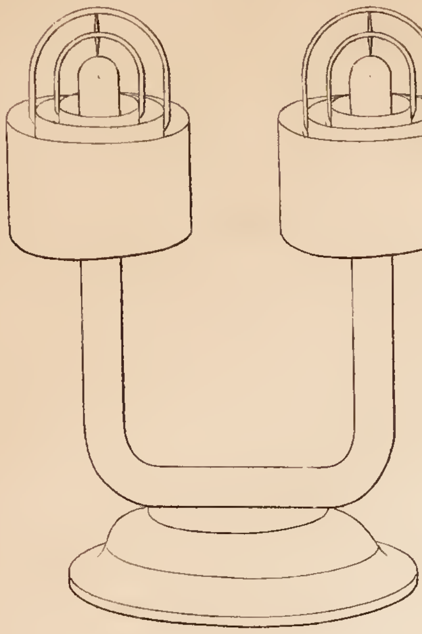


Fig. 20.

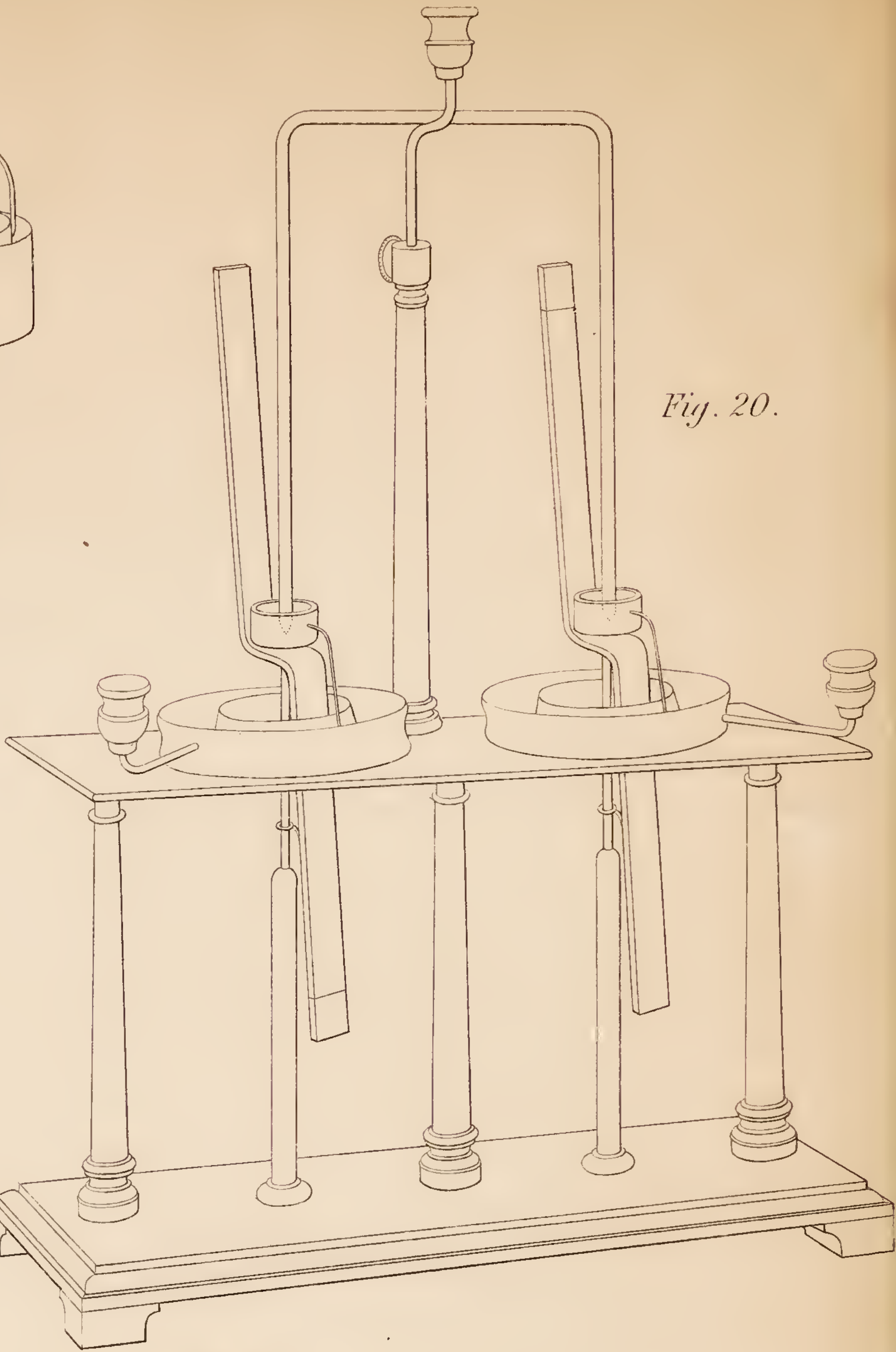


Fig. 21.

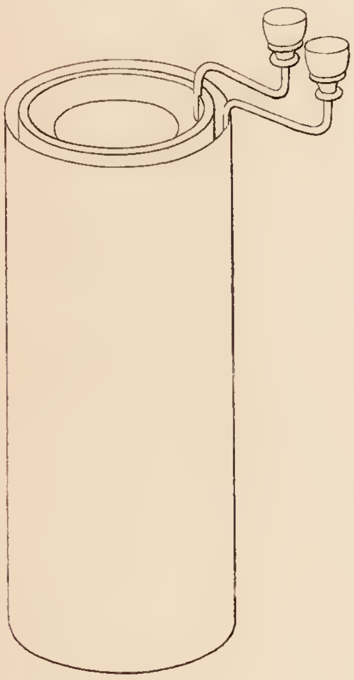


Fig. 23.

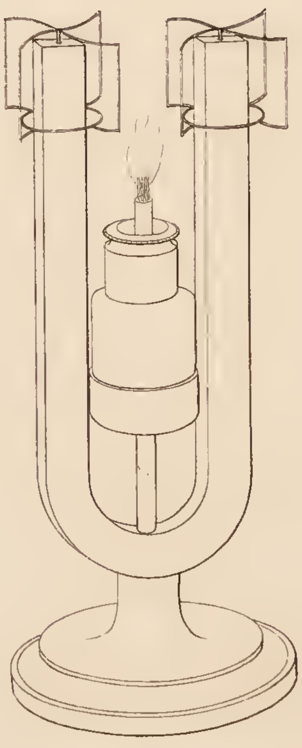


Fig. 22.

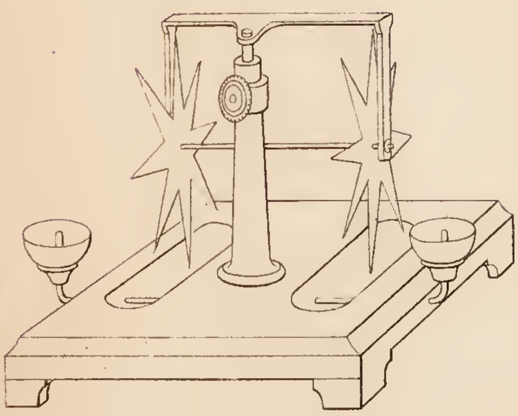
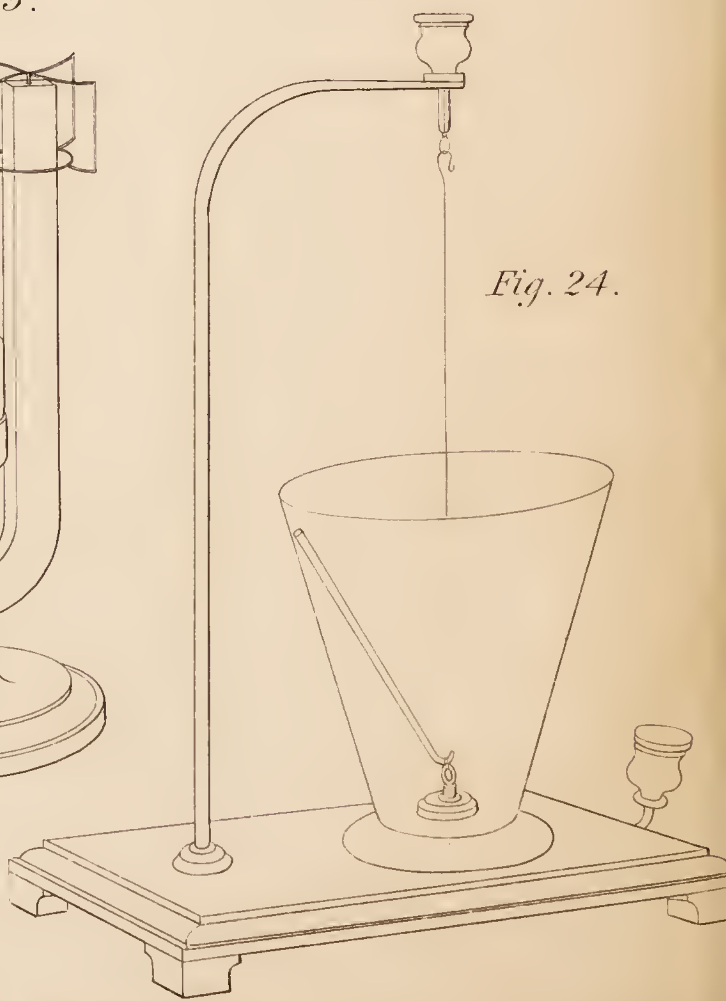


Fig. 24.



Published, July 1st 1828, by Watkins & Hill, Charing Cross, London.

E. Turrell,

the apparatus, the helical coils revolve rapidly in contrary directions; but on changing the disposition of the connecting wires, the revolutions of the coils will be reversed. The points of the various wires must be very clean or amalgamated, and the mercury in the cisterns and cups free from dirt.

Fig. 19. plate III. represents an apparatus constructed to exhibit the rotation of electrified wires about the poles of a horseshoe magnet, independent of a separate voltaic battery. It consists of a horseshoe magnet, firmly affixed to a metal foot at its bent part; its two ends being made rounding, and having a small hole in the centre of each, at the bottom of which hole an agate cup is placed, and in which, pointed wires affixed to the parts hereafter to be described are made to revolve. A double cylindrical copper vessel, having a bent metal wire affixed to the top of its innermost cylinder, with a vertical wire pointed at both ends, affixed in the middle of that bent wire, is hung upon the upper end of each pole of the magnet, the lower points of the vertical wires of each vessel entering the holes formed, as above described, in the magnet for that purpose. Two hollow cylinders of zinc, each furnished with similar bent wires, having holes made in the underside of each, are then placed within the double copper vessels; the holes in the bent wires being hung upon the uppermost pointed ends of the vertical wires before mentioned. A dilute acid being then poured into the space between the two copper cylinders, the voltaic action commences, and presents the phænomena of the whole of the four cylinders revolving upon their axis; the copper vessels revolving in opposite and contrary directions, and the zinc cylinder turning in opposite directions to them; the rapidity of their revolutions depending upon the strength of the diluted acid and the delicacy of their suspension. It is evident that a single pair of cylinders may be hung upon one end of a straight or bar magnet placed vertically, and will perform in a similar manner; their rotation being reversed on changing the poles of the magnet. Or a single pair of cylinders may be hung upon either end of a horseshoe magnet if preferred.

Fig. 20. plate III. represents an apparatus which exhibits the contrary poles of two magnets rotating about two electrified wires. Two flat bar magnets, doubly bent or curved in the middle of each, and having under the inverted part of each an agate

cap fixed, by which it is supported upon an upright pointed wire, affixed in the basis of the apparatus, and upon which it turns round as upon an axis. Above the agate cups, cisterns to hold mercury are also formed. Two circular troughs to contain mercury are supported upon a stage affixed to the basis, having holes in their centres to allow the magnets to pass through them. A bent pointed wire is affixed into the cisterns of each magnet, the ends of which dip into the mercury contained in the troughs upon the stage; and through the sides of the troughs wires are passed, entering into the mercury contained in the troughs, and bearing at their ends other cups to hold mercury. To steady the motions of the magnets, wire loops are affixed to them, which embrace the upright pointed wires upon which the magnets rest. A hollow pillar is firmly affixed to the stage, in which a bent wire supporting another cross wire is inserted, and is capable of being raised or lowered, and secured, at any required height, by a binding screw. The two ends of the cross wire are bent downwards, and pointed, and made to enter the two small cisterns affixed upon the magnets. A third cup to contain mercury is also provided at the top of the cross wire; and a communication being made with the voltaic battery in action, by means of uniting wires dipping into the mercury in the cups, the wire from the copper or plus extremity of the battery being placed in the upper cup, and one from the zinc, or minus extremity of it, in each of the lower cups,—the magnets will begin to rotate in opposite directions; and those directions may be reversed, by changing the situations of the uniting wires. Two batteries should be here employed, in order to make both the magnets revolve with the desired velocity: and attention must be paid when using two batteries, that the currents of electricity flow in the same direction; otherwise the phænomena of the revolutions of the magnets in contrary directions will not take place, but they will both revolve in the same direction.

Fig. 21. plate III. shows the cylindrical-form battery, which is strongly recommended for electro-magnetic experiments. It consists of a double cylindrical vessel made of thin copper, with a bottom of the same metal. In this vessel a moveable hollow cylinder of zinc is placed between the outer and inner surfaces of the double copper vessel, and is kept from coming into contact either

with those surfaces, or with the bottom of the vessel, by resting upon three wooden feet thick enough and high enough to insulate it. To the inside of the top of the outer copper cylinder, a copper wire is soldered, having at its outer end a small cup to contain mercury, the wire coming through the bottom of the cup into contact with the mercury. To the upper edge of the zinc cylinder another similar wire and cup are also affixed, to contain mercury. When a diluted acid solution is poured into the copper vessel, the voltaic action commences; and the electric current may be readily transmitted through an apparatus by means of two bent copper connecting wires by one end of each being inserted into the mercury contained in the cups fixed to the zinc and copper cylinders, while their other ends are in the mercury placed in the cups attached to the apparatus. The flow of the electric stream may be cut off or renewed at any moment, by removing one end of either connecting wire from its cup, or by replacing it again. In some cases, it is required to change the order of arrangement, so as to cause the current of electricity to flow in a contrary direction. This is readily effected, by merely changing the wires from the one cup to the other, which instantly reverses the action. It is necessary that the extremities of these connecting wires should either be perfectly bright, or else be amalgamated with mercury; the ends of the wire arms which support the cups, and enter the mercury in them, must also be in a similar state in order to preserve a perfect metallic contact. In general, one battery will be found sufficient; but when the apparatus is large, and consists of many parts, it is preferable to employ two.

Fig. 22. plate III. shows an apparatus intended to illustrate the rotatory motion which electrified metallic plates of a star figure acquire when under the influence of a horseshoe magnet or magnets. In the centre of the wooden basis is firmly fixed a hollow brass pillar, in which a bent cross piece is inserted, capable of being elevated or depressed, and secured at any required height, by a binding screw. The ends of the cross pieces are bent at right angles in the same direction and pendent, having a slit to pass the axle of the wheels to the circular cavities made to receive them. The compound plates are composed of flat copper pieces, pointed, and proceeding from the centre as radii; the extremities being equidistant from each other. A wire passes through the centre of

each plate and is attached as an axle; upon this the plates turn in the cavities at the bottom of the pendent arms of the cross piece. Under the pendent arms two oblong troughs are made in the wooden basis to contain mercury; metal cups to hold mercury are affixed to two wires, which proceed from each side of the basis, and penetrate into the mercury contained in the oblong troughs. When sufficient mercury is poured into these troughs, so that the points of the plates just touch it,—if two connecting wires passing from the zinc and copper extremities of a battery be placed in the cups, an electric current is established through both plates by the axle; but no motion will be produced, until two horseshoe magnets are placed with their poles extending underneath the axle, and resting on the basis of the apparatus. When the similar poles of the magnets are interior and exterior of the plates, then the plates will rotate rapidly; the course of rotation being reversed, by reversing the order of the connecting wires, or by changing the direction of the magnetic poles. To ensure perfect contact, the tips of the radii should be amalgamated, as should also the points of the wire which support the metallic cups. One powerful magnet will be sufficient to produce the effect.

Fig. 23. plate III. represents an apparatus to exhibit the rotation of two compound rectangular metallic frames about the poles of the magnet, by the mutual influence of a thermo-electric current and magnetism. It consists of a horseshoe magnet supported in a vertical position, upon a brass foot; through a hole made in the curved part of which, a wire passes from the foot, and supports a spirit-lamp. In the centre of each upper end of the magnet, an agate cup is cemented, in which turns a vertically pointed wire, to the upper end of which two crossing rectangles, or light compound wire frames, are united, composed either of silver and platinum, or platinum and copper; and are united below to wire circles, which surround the arms of the magnet. When the lamp is lighted, the flame heats the lower corners of the rectangles next to it, or rather within it: a thermo-electric current is thereby established in these rectangles, and by its action causes them to rotate in opposite and contrary directions.

Fig. 24. plate III. represents an apparatus which exhibits the electrified wire and magnet revolving about a common axis; the extremities of which axis are the vertices of two opposite cones,

the one generated by the wire, and the other by the magnet. It consists of a wooden stand, supporting a bent brass arm, at the upper end of which a vertical screw is passed through a screwed hole made in the arm. To the lower end of this screw a platinum loop is soldered, and a fine platinum wire is hung to that loop: to the upper end of the screw a cup to hold mercury is affixed. A glass vessel, having a hole perforated through its bottom, is placed upon the wooden stand, which has a corresponding hole made through it; a wire, bent up at each end, is secured underneath the bottom of the stand, and one end of it passing through the holes in the stand and in the glass-vessel, has a hole made in its end, to which a small magnet is looped, or fixed so as to play freely. The wire has a screw upon it, and a screwed nut, by which it is made tight. To the outer turned-up end of the wire, a cup to contain mercury is also affixed. Mercury being then put into the glass vessel, to a sufficient height to reach the lower end of the platinum wire, and a communication with a voltaic battery made in the usual manner by connecting wires, the wire and the magnet will then revolve in conical surfaces, having their points of suspension as vertices; and their directions may be changed by reversing the connecting wires.

THE END.

Printed by Richard Taylor, Red Lion Court, Fleet Street.